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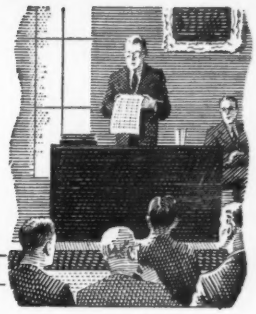

SIXTH HATFIELD MEMORIAL LECTURE

The Flow of Metals

By Professor E. N. da C. Andrade, F.R.S.

I COME before you both flattered and embarrassed by the honour which you have done me in inviting me to give the Sixth Hatfield Memorial Lecture. Flattered, naturally, both by being associated with the distinguished men who have delivered this lecture in past years and by being allowed to play a part in perpetuating the memory of a man so much esteemed and so much beloved by those who knew him as W. H. Hatfield. I can claim but a slight personal acquaintance with him, but we had, at least, one experience in common. He records that on Monday morning, 16th December, 1940, he arrived to find his research laboratories blasted by enemy action : a few months before, my own laboratories had suffered the same fate and with them disappeared some early notes, never published, of which I should have liked to lay the substance before you today. I can also say that Hatfield was interested in the theme that you have proposed for my lecture. As our friend Dr. Desch says in the obituary notice that he wrote for Hatfield, " A metallurgist dealing with steam turbines and other machines which work at a high temperature is faced by the problem of creep," and Hatfield concerned himself with working out a practical test which should, although taking only a short time, allow the long-range creep behaviour of steels to be estimated.

This brings me to my second point—I have said that I am not only flattered by your invitation but embarrassed. The source of my embarrassment is not my general inadequacy, but that you are mostly practical men, concerned with the behaviour of metals, in particular iron and steel, and, no doubt, hope—without, perhaps, any very strong confidence—that I will be able to tell you something of direct application to your daily problems. I have, however, been engaged in attempts to find out and explain the fundamental physical features of the flow of metals and, in consequence, have handled a variety of metals of a simpler nature than steel, some of them very pure, under simple systems of stressing. I aspire eventually to put in your hands certain general principles which you will be able to apply : I even venture to hope that some of the results so far obtained may interest you enough to hold your attention. I feel, however, rather like a physiologist or biochemist come from the laboratory to address a body of practical doctors, who have to cure people without knowing too much of the chemistry or physics of the cell. They cannot postpone the treatment of disease until its nature is understood, but nevertheless in the laboratory work may be the seeds of medical advance. And, indeed, perhaps the body and a metal have certain analogies. Every bit of metal is different from every other bit of metal, even if chemical analysis gives the same composition : metals show fatigue and have memories of their previous treatment : metals are even subject to disease, like intergranular fracture. The crystal grain and the body cell have certain analogies. Some of you may even be disposed to contend that metals have a certain unreasonableness and inconsistency not unlike that exhibited by the human polycrystalline mass.

THE problem for the practical engineer and the metallurgist interested in creep is to be able to predict the slow movement of stressed metals in diverse circumstances, over a long period, from a limited range of tests, frequently short-time tests. The problem for the physicist is, starting with the simplest metals, to break down the creep into its component factors and to discover how they are governed by temperature, crystal form, grain size, the

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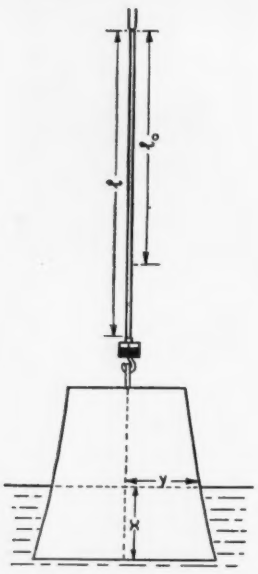


Fig. 1—Hyperbolic weight for maintaining constant stress

process of recrystallization, the distribution of external stress and local stress, and other circumstances. Only when these are understood can the effect of alloying and the structural modifications that it produces be profitably studied from the point of view of fundamental properties.

When as a young man I first took up a subject that has interested me ever since, in such leisure as wars and other circumstances have left me, I was convinced that matters would be greatly simplified if the observations were carried out under conditions of constant stress. The simplest way of testing a metal for creep would appear to be to load the rod or wire and measure the rate of extension, but if the load is a constant weight, and extensions of some per cent. are in question, with corresponding decrease of area of cross-section, the load per unit area, or stress, will increase, and since, as we shall see, certain factors in the creep are very sensitive to stress, the increase of stress is an added complication. I begin, then, by emphasizing the advantages of working at constant stress and describing briefly a few devices for maintaining it.

In the early days I used a device which consisted of a weight in the form of a hyperboloid of revolution, which sank in a suitable liquid as the wire extended, the upthrust reducing the load in the required proportion.[1] The disadvantage of this method (Fig. 1), which works very well, is that, with a given initial length of wire, one weight can be used for a small range of stresses only. A second method (Fig. 2*a*) first used in work which Dr. Bruce Chalmers and I carried out together,[2] has the advantage that, with a given initial length of the test specimen, one unit of apparatus will suffice for all loads. The load is applied by means of a beam *PH*, similar to that of a balance, resting on a knife edge at *B*. At one end is a plate *C* with a profile in the form of a circular arc, centre *B* : at the other end a plate with a profile *PQR*. The pull is transmitted to the specimen by a flexible metal strip fastened at *H* and touching the surface of *C* as the beam tilts. The load is applied by a weight *W* attached to a metal strip made fast at *P* and lying along *PQR*, the form of which is such that the moment of *W* is diminished as the beam tilts so as to be inversely as the length of the wire. Figure 2*b* shows a modification of the Andrade–Chalmers test bar for use when the specimen is to be pulled downwards. A very useful modification of this device has been made by Hopkin[3] and is shown in Fig. 3 : a battery of these is in use at the British Non-Ferrous Metals Research Association. Another constant-stress device is intended for extending the two ends of a horizontal specimen equally in opposite directions, so that the centre remains in position for microscopic observation (Fig. 4) : it is an amusing little bit of geometry.[4] Still another device has recently been perfected for tests of long duration where the extension may be considerable.

Perhaps, to emphasize the importance of constant stress, I may show you an old diagram contrasting the extension under constant stress and under constant load (Fig. 5). The extension here is large, so that the effect appears in exaggerated form, but it is quite significant for extensions of a very few per cent. only.[1] As Orowan[5] has pointed out, testing under constant load is not even sound from the engineer's

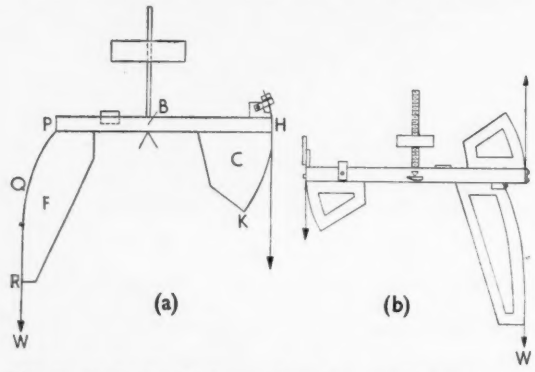


Fig. 2—Andrade–Chalmers bar for maintaining constant stress

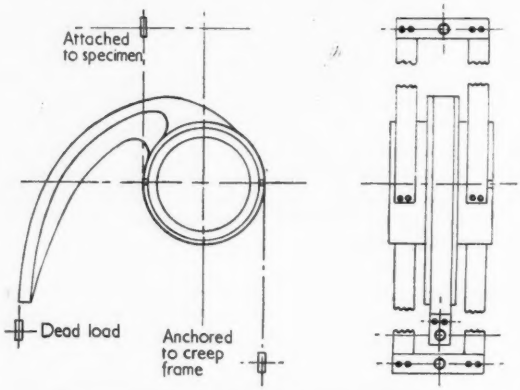


Fig. 3—Hopkin's constant-stress cam lever

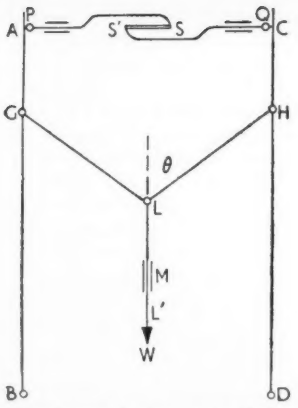


Fig. 4—Constant-stress device maintaining the central points of the specimen stationary. The specimen is *S'S*, and *P*,*Q*,*G*,*L*,*H*,*B*,*D*, are pivoted joints

point of view, since in compressive loading the creep curve at constant load deviates in the opposite sense from that in tensile load.

The result of the measurements made in the years before the first world war[1,6] was that the creep of a variety of metals, *measured as the extension of a normal polycrystalline wire under constant stress*, could be expressed by one simple equation :

$$l = l_0(1 + \beta t^{\frac{1}{3}})e^{\kappa t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The exponential nature of the term $e^{\kappa t}$ is due to the fact that the length of the wire which is creeping is continually increasing, so that a constant rate of creep per unit length gives an increasing rate for the wire as a whole. Taking $\beta = 0$, we have

$$\frac{1}{l}\frac{dl}{dt} = \kappa$$

or, at a given stress, κ expresses a flow of constant rate per unit length, which may be called a quasi-viscous behaviour—quasi-viscous, because κ is not proportional to stress.*

This analysis thus distinguishes creep into two physically distinct components, the β, or transient creep, which, being proportional to the cube root of the time, diminishes rapidly in rate as time goes on,

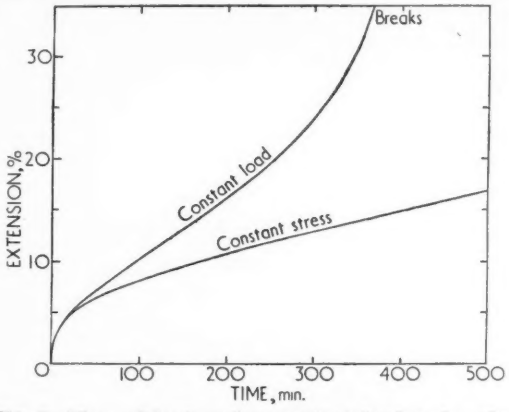


Fig. 5—Flow of lead under constant load and under constant stress contrasted

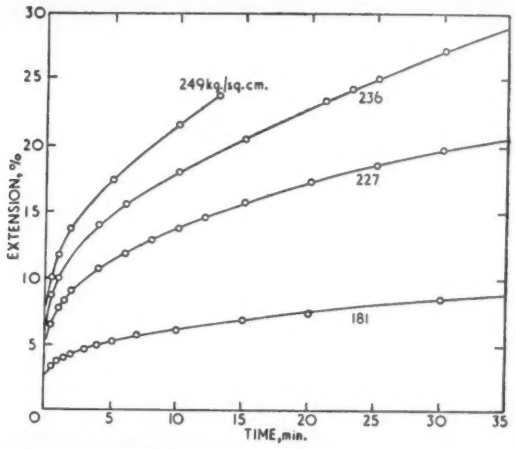


Fig. 6—Flow of lead under constant stress at 17° C.

and the κ, or permanent creep, which proceeds at a constant rate per unit length. There is an immediate extension, expressed by the fact that l_0 is not the original length of the wire. This immediate extension is important, but I shall not discuss it now.

Since the creep under tension of the various pure metals tested—lead, tin, copper, iron, cadmium, and solid mercury, the last-named being selected for its particular purity—obeys the same equation, it may be asked why, for instance, copper and lead are generally taken to behave quite differently, as far as creep is concerned. The reason is that experiments are usually carried out at atmospheric temperature, at which the two metals are certainly in marked contrast. If, however, we compare copper at a high temperature with lead at room temperature, or lead at a low temperature with copper at room temperature, we find the behaviour very similar. Let us look at the curves for lead at various temperatures. In Fig. 6 we have lead at room temperature : the β and the κ flow are both well marked, and we have typical constant-stress curves. For lead at low temperature (Fig. 7) we have curves at − 180° C. and − 78° C. At − 78° C. there is large immediate extension,

*It may be remarked that the exponential term has been misunderstood. For instance Tyte, working at constant load instead of constant stress, used it to express the flow in circumstances where any increase in rate must be due rather to increase in stress than to increase in length.

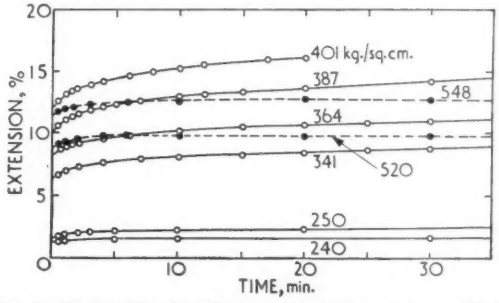


Fig. 7—Flow of lead under constant stress at − 180° C. (broken lines) and at − 78° C. (full lines)

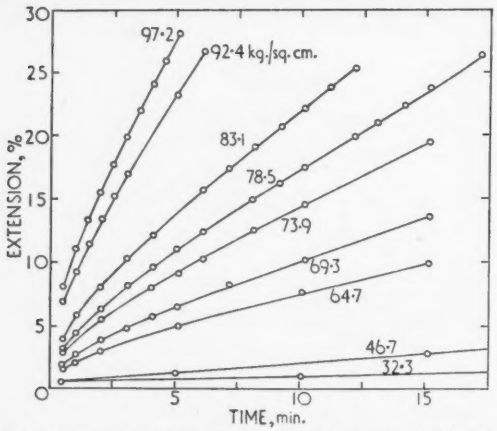


Fig. 8—Flow of lead under constant stress at 160° C.

followed by a pure $t^{\frac{1}{3}}$ flow ; at — 180° C. the immediate extension is even more predominant, compared with the very small $t^{\frac{1}{3}}$ flow. At 160° C. it is the κ flow that is predominant : after some minutes the flow curves approach straight lines (Fig. 8). But now let us look at a diagram where the flow of lead at 17° C. is compared with that of iron at 444° C. (Fig. 9). The resemblance in type of the flow curves is clear at once. Similarly, the flow of lead at — 180° C. closely resembles that of copper at 15° C. (Fig. 10). The one formula covers all the cases, but the relative importance of l_0, β, and κ varies markedly with the temperature. A rough rule which I have found of use in considering many aspects of the mechanical behaviour of metals is to take as the significant, or reduced, temperature θ, the ratio of the temperature in question to the temperature of melting, $\theta = T/T_m$, both measured on the absolute scale.[7] Thus for lead at — 180° C. θ is 0·16, for copper at 15° C. θ is 0·21 : for lead at 15° and iron at 444° C. θ is, respectively, 0·48 and 0·40.

The criticism has been raised that my experiments are of relatively short duration, of a few hours only, which is true. Dr. Hopkin[3] has, however, carried out experiments on the creep of pure lead, using a constant-stress device, and has found very close agreement with my formula over a duration of 1000 hr., the total extension being 18%. With a lead containing tin he likewise verified the formula, the duration of the test being 500 hr.

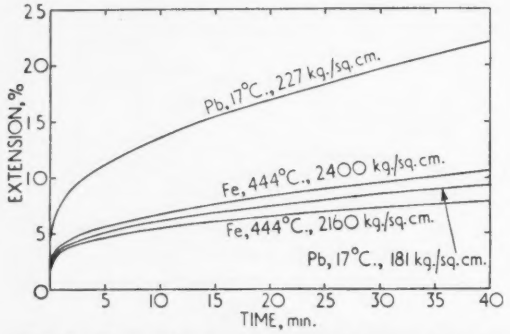


Fig. 9—Flow of lead at 17° C. and of iron at 444° C.

Let us consider a little further these characteristic constants β and κ, which determine normal creep. First of all, how do they vary with stress and with temperature ? Figure 11 is a diagram from an early paper[6] showing the variation of β with stress for lead at different temperatures. It appears that β reaches a limit with stress and that this limit is independent of temperature. I have recently been examining old results on the subject, and have found some new and interesting regularities. First of all it appears that for the one particular metal, lead, for which sufficient results are available, one curve can, by a suitable change of the scale of stress τ, be made to give the variation of β with τ at constant temperature for a wide range of temperatures, *i.e.* :

$$\beta = f(q\tau)$$

where q is a constant dependent on the temperature. I have derived a simple formula expressing this dependence, but I will not detain you with this detail now. I have further found that the sigmoid curve is fairly well represented by

$$y = \int_0^x x^2 e^{-x^2}\, dx$$

the form of which is shown in Fig. 12.

Again, if we change the scale of β as well as the scale of τ, the same sigmoid curve will answer well for a range of other metals, *viz.*, copper, iron, and cadmium.

This sigmoid curve, then, is characteristic of the β, τ relation for many metals and a range of temperatures. This can be explained on general lines by supposing the metal to contain points of weakness or faults, each characterized by a yield stress, the distribution of which according to stress x is given by the probability curve $y = Ae^{-x^2}$, while the contribution of each fault, when it yields, to the creep is proportional to x^2. This is not an occasion on which to discuss such points in detail, more particularly as I am struggling with certain aspects of this theory. What I wish to do is to convince you that there is a certain generality in the behaviour of β which gives us hope of a further insight into the mechanism of creep.

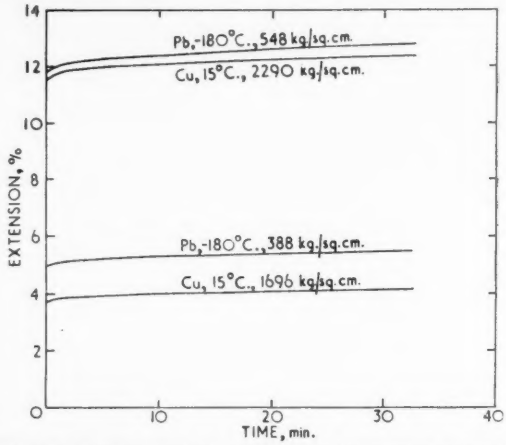


Fig. 10—Flow of lead at — 180° C. and of copper at 15° C.

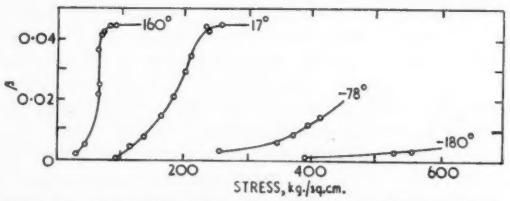


Fig. 11—Variation of β with stress and temperature

Turning to the permanent creep, we find that log κ is linear with stress. This is particularly well shown (Fig. 13) by some old results of mine on the creep of a lead–tin alloy (fuse wire, 21·5% Pb, 78·5% Sn). The law is quite general : Fig. 14 shows the results for copper at 410° C. This law means, of course, that κ increases very rapidly with stress. There have been ingenious attempts to deduce theoretically a general law giving κ in terms of stress and temperature.[8] Here I shall only insist that κ increases very rapidly with temperature as well as with stress. You have seen that, on the other hand, β reaches a limiting value with both. The general character of the creep curves of pure metals is now clear : at very low temperatures κ is zero, and β is small for all possible stresses : we have in general a large immediate extension and a small transient creep according to $t^{\frac{1}{3}}$. At somewhat higher temperatures κ is still zero, and β attains larger values for higher stresses. There is marked transient creep. At still higher temperatures we have β and κ both playing their part, and the typical transient creep survived by permanent creep, as shown by the behaviour of lead at room temperature. At still higher temperatures the β creep has reached its limit and is relatively unimportant : it is the permanent creep that predominates throughout.

The $t^{\frac{1}{3}}$ law is of great generality and has proved valid for a wide range of substances. Theoretical physicists, on the basis of elaborations of the dislocation theory, have deduced exponential formulae to express transient creep, but, interesting and impressive as they are, they do not agree well with experiment. As a young man I tried many variants of exponential formulae, suggested by Boltzmann's work, before arriving at $t^{\frac{1}{3}}$. A careful comparison by Dr.

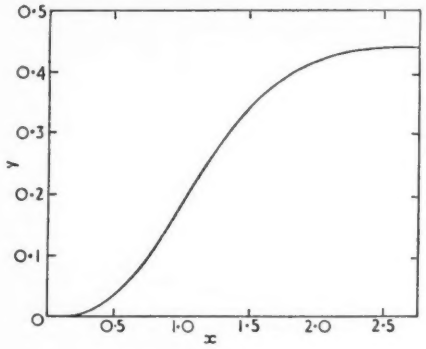


Fig. 12—$y = \int_0^x x^2 e^{-x^2} dx$, to which the β–τ curve approximates

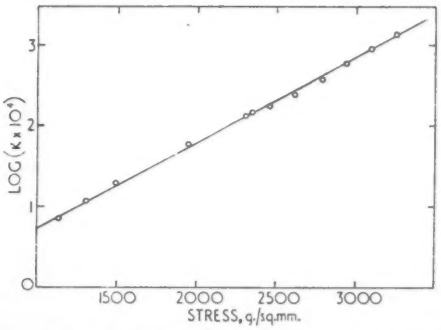


Fig. 13—Log κ against stress for the creep of a lead–tin alloy (fuse wire) at 15° C.

Jolliffe and myself of the various proposed formulae has established a much closer agreement with the $t^{\frac{1}{3}}$ formula than with the other formulae. Dr. A. J. Kennedy has recently made an examination of the record of transient creep, not only for various metals, but also for miscellaneous substances—mortar, concrete, plasticized polyvinyl chloride, cuprammonium filaments, celluloid, nylon, rubber, and fabric-filled phenoplast. In all cases the results are in excellent accord with the $t^{\frac{1}{3}}$ law. Further evidence for its validity will be produced when I discuss creep under simple shear.

The transient and permanent flow, expressed by β and κ, have different physical mechanisms. Broadly speaking, the β flow is attributable to slip on glide planes within the crystal grains : it is a matter of adjustments within the grains. The permanent creep, on the other hand, is due to a relative adjustment of grains as a whole relative to one another : it is a boundary effect. The important experiments of Hanson and Wheeler,[9] who worked with aluminium, have shown that under conditions favourable for marked β flow, close systems of slip bands are well developed within the grains, whereas under conditions favourable for permanent flow, with little β flow, there is comparatively little glide within the grains, but marked boundary effects, in the nature of broadening and emphasizing the boundary, with ultimately the development of intercrystalline cracks. Thus at 250° C. rapid straining to an extension of 20% produced very marked slip bands, whilst the same strain effected in 210 hr., which would be mainly due to permanent creep, gave only boundary effects. Long ago I showed that a rapid preliminary extension or

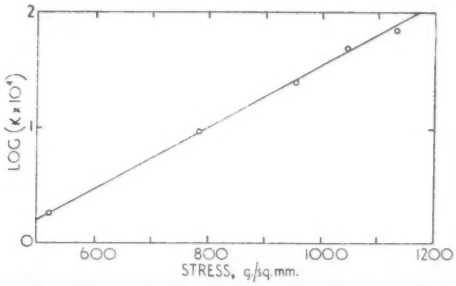
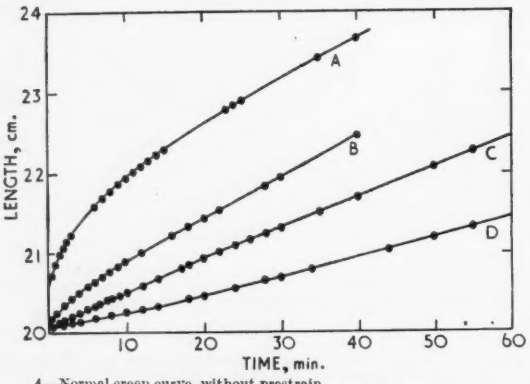


Fig. 14—Log κ against stress for copper at 410° C.

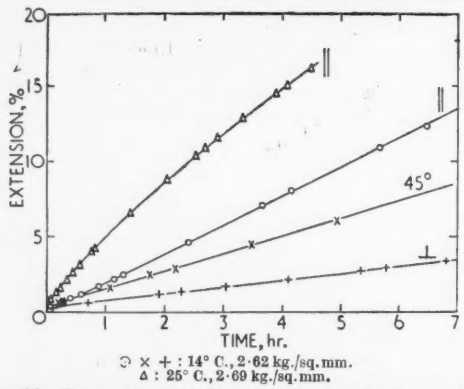


A—Normal creep curve, without prestrain
B, *C*, and *D*—After 10% prestrain, effected at 100°, 35°, and −180° C., respectively

Fig. 15—Influence of rapid prestrain on subsequent creep, with tellurium–lead at 35° C.

torsion—in fact, "any form of severe preliminary strain"—would put a wire in a state to flow linearly with time from the start.[6] Recently Dr. Kennedy[10] has made a careful study of the effect of a rapid preliminary extension on subsequent flow under constant stress, with the interesting result that after such extension the flow can be represented by the same values of β and κ as hold for a normal wire, if for t we substitute $t + t_0$, where t_0 is a constant the value of which increases as the preliminary strain increases. In other words, the rapid strain exhausts a part of the β-flow mechanism, and a large strain exhausts it completely, leaving only the permanent creep. He also showed that a given prestrain was the more effective the lower the temperature at which it was effected, as shown in Fig. 15, which agrees well with the views that I have put forward. Thus β flow can be completely eliminated.

Another expression of the effect of prestrain is afforded by the experiments carried out by Dr. Charmian Sinclair on the flow of strips cut from rolled sheets of commercial cadmium. The rolling is well known to effect a preferential orientation, in the case of hexagonal metals tending to set the basal plane parallel to the sheet surface : the process also produces elongated grains, with their longest direction in the direction of rolling. Figure 16 shows the flow at 14° C. under constant stress of strips cut from a rolled sheet parallel to, at 45° to, and normal to the direction of rolling. In the normal and 45° cases we have a perfectly uniform rate of flow : in the parallel case there is a very slight acceleration, scarcely perceptible in the diagram, in the first hour, after which the rate is constant. With elongated grains it is to be anticipated that glide will be easier when the stress is parallel to the long direction than when it is normal, since the case more nearly approaches that of a single crystal. The value of κ for the flow at 45°, at the temperature and stress in question, agrees within experimental error with that given by the polycrystalline wire at the same stress and temperature. These results show the elimination of β flow by orientation of the crystal grains.



○ × + : 14° C., 2·62 kg./sq.mm.
△ : 25° C., 2·69 kg./sq.mm.

Fig. 16—Creep of specimens cut from rolled cadmium sheet, parallel to, at 45° to, and normal to direction of rolling

By other methods κ flow can be eliminated, leaving only the $t^{\frac{1}{3}}$ type. A small addition of tellurium to lead gives a metal showing only β flow at atmospheric temperature,[11] and later I shall describe experiments showing that a certain method of stressing produces pure $t^{\frac{1}{3}}$ flow with metal that under the normal method of test shows combined transient and permanent types of flow. Thus the physical distinctness of the two types is well established.

We may fairly claim, then, that for simple metals the flow can in general be well expressed by formula (1) which resolves it into an immediate extension, a transient or β creep, and a permanent creep, which means that finally the rate of extension per unit length is constant. Many workers, however, distinguish a fourth state, during which creep proceeds at an ever-accelerating rate. Such accelerated creep is, in most tests, due to working with constant load rather than with constant stress, as I have already pointed out. It can, however, occur when the extension is so small that the decrease of cross-section, and consequently the increase of stress, is insignificant. An example is, for instance, given by the creep curves for a high-nickel, high-chromium steel at 800° C., taken from a report by Tapsell and Remfry[12] (Fig. 17). There is a final stage of marked acceleration at a stress of 3·2

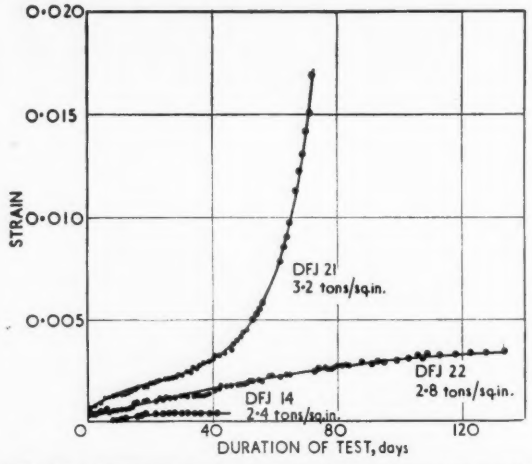


Fig. 17—Creep of a high-nickel–high-chromium steel at 800° C.

tons/sq. in. (500 kg./sq. cm.), beginning when the strain is about 0·25%, while at the smaller stress and final strain there is no acceleration. I think that there can be no doubt that such acceleration is due to recrystallization under strain. The word ' recrystallization ' is used in different senses : I use it here for a process of grain growth during which large crystals are formed by the transfer of atoms from various smaller domains. Greenwood and Worner[13] have obtained in tests of long duration with rolled lead creep curves very similar to *DFJ* 21 in Fig. 17, and state that the behaviour is associated with certain solute atoms. However, as the percentage extension went up to 15 or 20%, and the tests were carried out at constant load, the rapid increase in rate towards the end of the test must be largely due to increases in stress, as reference to Fig. 5 will confirm. They refer to recrystallization, but do not appear to have established that the increased rate is particularly associated with a rapid rate of recrystallization. They established, however, the occurrence of recrystallization during accelerated flow in another type of abnormal creep curve with rolled lead. Dr. Charmian Sinclair and I carried out some time ago a series of careful experiments on creep of short duration with extended wires of a very pure (Tadanac) lead at various temperatures. The metal was strain-free and of uniform grain size, of about 100 grains/sq. mm. X-ray photographs gave no evidence of preferred orientation. This lead does not recrystallize if left unstrained at ordinary temperatures, but it does recrystallize under stress, or, as we shall see it is better to say, under strain. At − 87° C. the flow under constant stress was of pure $t^{\frac{1}{3}}$ form. At 0° C. there was a stage of marked acceleration, followed by a deceleration of the β type (*see* Fig. 18), or we can say that the first hardening was followed by a softening, succeeded by a second hardening Failure was by necking, leading to a characteristic knife-edge fracture. It was established that the first stage at which new grains were observed corresponded to the first acceleration and that when the curve finally took the form of a normal creep curve recrystallization was complete. X-ray examination showed that the large grains formed had a preferential direction of axes that did not differ very much in adjacent grains : this was confirmed by the appearance of the glide planes formed. The extension/time curves at 20° and 25° C. were similar to those at 0° C., but the time intervals to the beginning of recrystallization, as indicated by the first sign of acceleration, were shorter : at 50° C. shorter still and at 100° C. the recrystallization took place almost instantaneously.

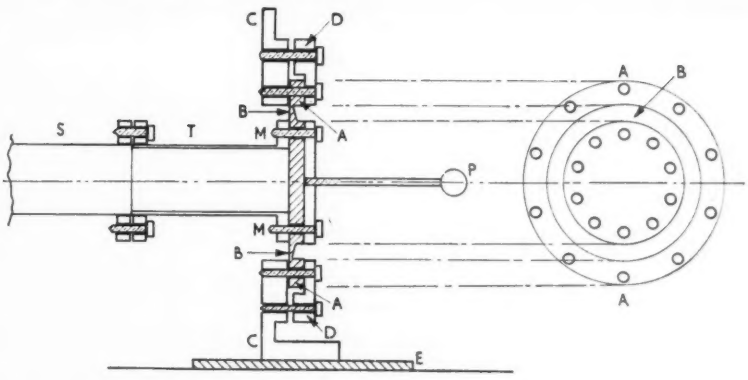


Fig. 19—Apparatus for creep under conditions of simple shear

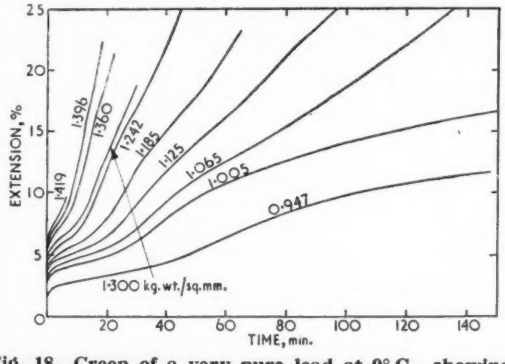


Fig. 18—Creep of a very pure lead at 0° C., showing effect of recrystallization

These experiments enabled us to establish the conditions that lead to recrystallization. Rate curves prepared from the extension curves give the first point of inflexion, where recrystallization commences, as a minimum. It appeared possible that the conditions for this point might be given by strain, rate of strain, or time from the imposition of load. It turns out that it is strain, independent of temperature over the range in which recrystallization is detected (0–100° C.), that is effective. The conditions for the effect can be expressed by the formula :

$$s = 4 \cdot 6 \tau^{1 \cdot 6}$$

where s is the percentage extension at which recrystallization commences and τ is the stress in kg./sq. mm. Recrystallization, then, would appear to depend in a rather complicated way on the amount of glide that takes place in the grains.

In the type of recrystallization investigated by us, a normal creep according to

$$= l_0(1 + \beta t^{\frac{1}{3}})e^{\kappa t}$$

is followed by a region of accelerated flow which diminishes to a roughly constant rate. I shall have to refer again to recrystallization under strain when describing our experiments on creep under simple shear, to which I now turn.

The stress distribution during the flow of a plastic rod under axial tension is not the simple matter that it might be supposed to be. Creep of a cylinder under torsion has the advantage that the direction of the stress can be easily reversed, and a long time ago I carried out some experiments on lead by this method, but the differences of conditions at different distances from the axis made the detailed interpreta-

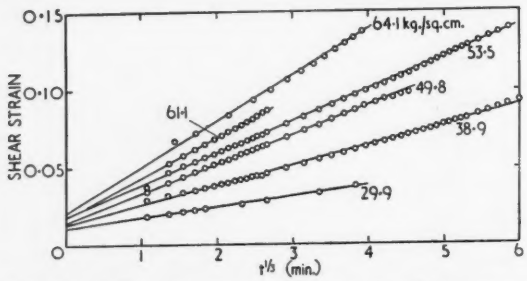


Fig. 20—Creep of commercial lead at 25° C. under simple shear shown as shear strain against $t^{\frac{1}{3}}$

tion difficult. Things are simpler when we work with an annulus under torsion, since, with suitable conditions, it is easy to measure the shear strain under simple shear, with possible reversal of the direction of the stress. In the experiments carried out by Dr. Jolliffe and myself[14] the disposition was as follows (*see* Fig. 19) :

In the test disc AA of polycrystalline metal, approximately 16 cm. dia. and 1 cm. thick, one face is accurately flat, while in the other a groove BB is cut. The rim of the disc is firmly clamped to a metal plate CC, which is bolted to a bed-plate, a sheet of poorly conducting material E being inserted to provide heat insulation. The part of the disc interior to the groove is gripped to horizontal shafts mounted in plummer blocks carried by the bed-plate : to the far end of the shaft is attached a wheel 50 cm. dia., by means of which a couple may be applied. The weights producing the torsion are carried by a flexible steel tape and things are so arranged that the sense of the couple can be quickly reversed. T is a tube of nickel steel, which has a low conductivity for heat. The disc and its supports are surrounded by a thermostatically controlled constant-temperature bath, not shown in the diagram. Thus the annulus of metal at BB can be subjected to simple shear in either sense. Since the area on which the shear acts is proportional to r, the distance from the axis, and the force is inversely proportional to r, the couple being constant, the thickness of the annulus of metal is made proportional to $1/r^2$, which makes the shear stress uniform.

Some remarkable results have been found with creep carried out under these conditions. The three metals used in this first investigation were a very pure lead, a commercial lead, and commercial cadmium, the grain size for the lead being in the region of 200 grains/sq. mm. and for the cadmium 600. The first

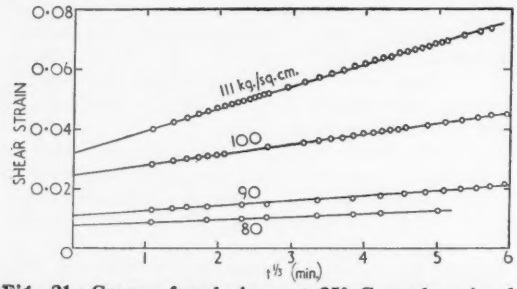


Fig. 21—Creep of cadmium at 25° C. under simple shear shown as shear strain against $t^{\frac{1}{3}}$

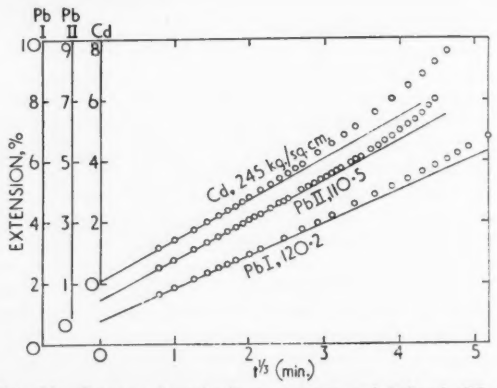


Fig. 22—Creep of cadmium, commercial lead (Pb I) and pure lead (Pb II) at 25° C. under tensile stress shown as percentage extension against $t^{\frac{1}{3}}$

finding is that, under these conditions, the shear strain γ is given very accurately by a pure $t^{\frac{1}{3}}$ law :

$$\gamma = A + Bt^{\frac{1}{3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

even at temperatures where, in tensile tests with the same metal, the permanent creep is marked. Figure 20 shows, for commercial lead, the shear strain against $t^{\frac{1}{3}}$, and Fig. 21 the same thing for cadmium. In contrast, Fig. 22 shows the elongation under the ordinary tensile test at constant stress of the same metals against $t^{\frac{1}{3}}$: it will be seen that without a permanent-creep term the departures become very large as time increases. Even at high temperatures the $t^{\frac{1}{3}}$ law is obeyed under conditions of simple shear, as is clear from Fig. 23.* At such temperatures in tensile tests the permanent flow, linear with time, predominates.

The very pure lead shows recrystallization effects of the same kind as those under tensile tests of which I have already spoken. Figure 24 shows the shear strain against $t^{\frac{1}{3}}$: it will be seen that the $t^{\frac{1}{3}}$ law holds up to a certain point, at which a marked

* The curves represent values calculated according to $t^{\frac{1}{3}}$, the points observed values. That these are not as consistent as at lower temperatures is probably due to the temperature control not being precise enough.

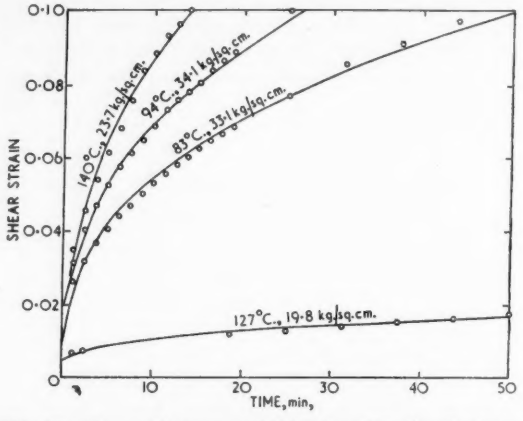


Fig. 23—Creep of commercial lead under simple shear at high temperature

increase in rate begins. The strain γ_r at which the recrystallization effect begins is given by

$$\gamma_r = 1{\cdot}21 \times 10^{-6}\,\sigma^{1{\cdot}7}$$

which is of the same form as the formula already given for recrystallization under tensile strain. The exponent cannot be fixed very accurately : it is possible that it is 1·66 in both cases, *i.e.*.., $1\frac{2}{3}$, which would bring in the fatal $\frac{1}{3}$ again.

The results under reversed shear are also surprising, and show a marked contrast between the behaviour of the cubic metal, lead, and the hexagonal metal, cadmium. No such contrast has ever been found in tensile tests. Both leads show in reverse a flow linear with time, there being no significant recrystallization effects in reversed shear with the pure lead. Cadmium, however, under reversed shear obeys the $t^{\frac{1}{3}}$ law, as in direct shear, and the same contrast between lead and cadmium is shown on a second reversal. The contrast is, perhaps, most plainly shown in Fig. 25, where the shear-strain/time curves are shown for a particular stress for each metal.

This difference of behaviour in reverse shear is capable of a simple explanation in terms of the properties of single crystals of the metals in question. With lead, glide takes place on the four octahedral {111} planes, with three possible ⟨110⟩ glide directions in each ; with cadmium the one set of basal planes is operative, with three possible glide directions. Now the critical shear stress of lead single crystals* is about 14 g./sq. mm. as against about 50 g./sq. mm. for standard cadmium, but lead, with the typical contrast between a cubic and a hexagonal metal, hardens very rapidly compared with cadmium, so that at 0·30 glide, for instance, the stress required to produce further glide is about 450 g./sq. mm. for lead as against 80 g./sq. mm. for cadmium. The many glide possibilities which exist for a crystal grain in lead mean that the grain can adapt its shape readily to the complex system of stresses and strains produced by the movements of the surrounding grains : there is little geometrical hardening but considerable physical hardening in the grains of the polycrystalline metal. With cadmium the limitation of glide to one plane means considerable geometrical hardening even if we allow for twinning, but there is little physical hardening (*see*, *e.g.*, Andrade and Roscoe[15]).

* Unpublished experiments by Mr. M. J. Makin.

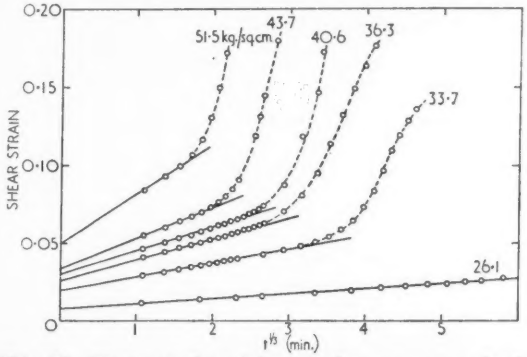
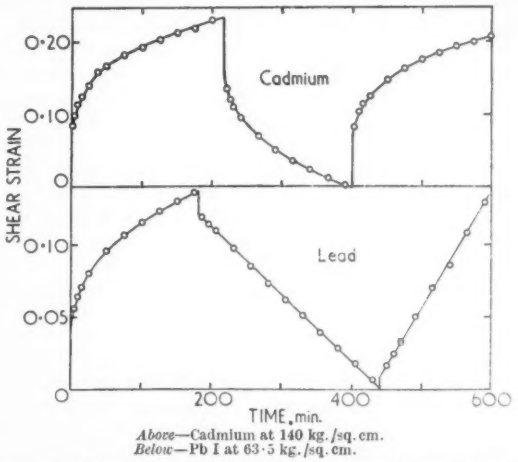


Fig. 24—Shear strain against $t^{\frac{1}{3}}$ for very pure lead at 25° C., showing effect of recrystallization



Above—Cadmium at 140 kg./sq. cm.
Below—Pb I at 63·5 kg./sq. cm.

Fig. 25—Contrast between the behaviour of commercial lead and of cadmium at 25° C. under two reversals of simple shear

The possibilities of geometrical adaptation offered by the multiplicity of possible glide planes and glide directions explain how it is that lead, which in single crystal form is, after a few per cent. glide, harder than cadmium, is in polycrystalline form so much softer, as measured by the value of B in formula (2) (*see* Fig. 26). It also explains why it is that, compared with cadmium, lead becomes progressively harder as deformation increases, hardness being for this purpose measured by $d\sigma/dB$, constant for lead but rapidly decreasing for cadmium. We do not yet know enough to explain the precise form of the B–σ relationship for the two metals.

After considerable forward shear the lead grains have greatly hardened and the boundary material has, owing to the rotation of crystal planes, been broken up, but the interlocking produced by the glide on four planes has prevented intergranular movement. When the shear is reversed, glide does not occur in the hardened grains, but intergranular movement can take place. With cadmium, however, the crystal grains are, as far as glide is concerned, much as they were in the forward movement and we have a repeti-

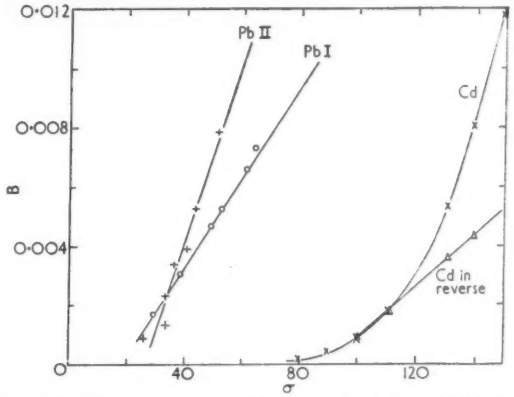


Fig. 26—*B* against stress for commercial lead (Pb I), pure lead (Pb II), cadmium, and cadmium in reverse

tion of the $t^{\frac{1}{3}}$ flow. There has, of course, been a certain amount of hardening in grains that have been much deformed by glide or twinning, which is a qualitative explanation of the fact that for large stresses there is hardening, as expressed by B', the value of B in reverse shear being smaller than B for large σ, although about the same for smaller σ. It is, of course, most desirable that a quantitative explanation of the variations of B with σ should be found, but this is not likely to eventuate until a convincing explanation of the $t^{\frac{1}{3}}$ law has been found.

If we express the flow of lead under reversed shear as $$\gamma = A' + K't$$ then it is found that $\log K'$ is linear with σ, just as $\log \kappa$ is linear with stress for creep under tensile stress. This supports the suggestion already put forward that we have here the same mechanism of movement in grain boundaries. In this reversed movement with lead we have pure linear flow with time, which gives us an opportunity of investigating in detail the variation of this flow with temperature and with impurities which segregate to the boundary.

I have spoken of the β flow as connected with intragranular glide and its consequences, and of the permanent flow as due to the movement of grains conditioned by boundary effects, that is, as if the two effects were separate. Such a complete separation is not, however, physically possible. Glide, and consequent rotation of the crystal planes within a grain is bound to modify the boundary, as I have illustrated with a model made of microscope slides[16] : the coarser the glide packets the more the boundary is broken up.* On the other hand the glide planes often do not run right to the crystal boundary (*cf.* Boas and Hargreaves[17]) which shows that the boundary has an effect on intragranular glide. The action of a given amount of glide in creating wider boundaries, mainly amorphous, will clearly be greatest when there is one set of glide planes only, as with hexagonal crystals, where we have also the possibility of twinning. I should like to be able here to develop the consideration of this interaction of the boundary and the intergranular glide so as to explain some of the problems offered by the variation of the constants B and β with stress, but I have not yet satisfied myself, and so am unlikely to be able to satisfy you.

One of the problems posed by these experiments under simple shear is : Why is there no permanent flow? A great physical difference between the shear and the tensile method of testing is that in the tensile method we have a free surface which is under stress and continuously moving normal to itself and at the same time increasing in area. Under simple shear the free surfaces are unstressed and remain in the same plane as strain proceeds : the surfaces across which the stress is applied are not free, but lie in massive metal. In the tensile case the grains at the surface are free to move, in particular to rotate, relatively to one another and this free movement at the surface promotes intragranular movement throughout the metal, with consequent adjustments, in the amorphous material, of the type discussed. In the shear case the crystal structure is locked at the edges of the annulus and deformations can, in the first case, proceed only by intragranular glide. Such glide, in the case of cubic crystals, both hardens the crystal structure in the glide planes and, as a consequence of change of inclination of the planes in neighbouring grains, creates amorphous material, as indicated in Fig. 27, where (*a*) shows, in a vastly simplified way, the boundary between two grains before glide, and (*b*) the position after glide. Reversal of shear stress tears the grains apart, as indicated at the lower boundaries of the glide packets in (*c*), and we then, with hardened grains and an extended amorphous interlayer, have conditions for permanent flow.

That the free surface has an important influence in tensile experiments has been confirmed by some preliminary experiments of Dr. Kennedy and myself.[11] We worked with lead to which 0·05% of tellurium had been added : with this metal there is no permanent flow except at the highest stress. The flow being thus characterized by β we found the variation of β with stress for wires of four different diameters—1, 2, 3, and 5 mm.—the grain diameter being about 0·2 mm. and so comparable with the wire diameter. At a given stress, the smaller the diameter of the wire, the larger was β, which is what we should expect if there were a relatively weak surface layer. It was found that the results could be quantitatively expressed as $$S = S_0 \frac{(r - na)^2}{r^2}$$ where S is the value of the stress corresponding to a given value of β, S_0 is the value towards which S tends as the radius of the wire becomes large, r is the radius, a the average grain diameter, and n a constant which turned out to be 0·3. This is equivalent to taking a surface layer of about one-third of the grain diameter as having no strength at all, a crude representation of a weak surface layer of greater thickness.

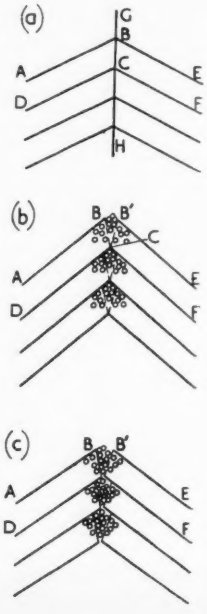


Fig. 27—Formal representation of effect of direct and reversed shear stress on grain boundary in a metal whose crystals harden markedly under glide

* If this picture is correct the density of a fine-grained hexagonal metal should decrease appreciably on rapid extension, a matter for experimental investigation.

The formula represents the results very closely : thus at a particular value of β the stress S is 66·0, 72·25, 75·2, and 77·3 kg./sq. cm., from low to high diameter, while S_0 comes out to be 82·1, 82·2, 81·8, and 81·7, a very satisfactory constancy.

The general lesson for the practical man from the experiments under simple shear is that the type of creep that occurs depends essentially on the system of stressing : that, for instance, a marked permanent creep shown by tensile experiments may not occur at all when the metal is stressed so that the free surface remains in the same plane and of the same area, while the stress is entirely transmitted through massive metal. Further, that the creep under reversed shear stress may be essentially different from that under direct stress, as shown by the results on lead.

Perhaps I may here say a word on another aspect of creep which may be of interest to practical men, namely, creep under intermittent stressing, on which Dr. A. J. Kennedy has just completed an interesting study.[18] I am afraid that the metal is our favourite polycrystalline lead, which offers a very favourable substance for study at atmospheric temperature. When such a metal is unloaded after a short period of creep it softens progressively, so that when it is restored it starts the new period of creep at a greater rate than that which prevailed just before unloading. Kennedy has worked out the creep under alternate periods of loading and unloading, which he has shown can be calculated in terms of one constant n in addition to β.* He tested his formula with tellurium–lead with alternate load periods of 160 sec. and off-load periods of 320 sec. The curve under continuous constant stress is shown by the broken line in Fig. 28, that under interrupted stress by the full line, both in the upper part of the diagram. Below is shown the length in both the interrupted and uninterrupted case plotted against $t^{\frac{1}{3}}$, where t in the interrupted case is the time under load. In the interrupted case the value of n was found to be 0·364 and the line is the calculated line, the solid circles being the experimental values. It will be seen that the agreement is very good. It is clear that after a short initial period the total creep in the interrupted case is greater than that after the same time of load in the uninterrupted case, which might have been expected on general considerations of recovery. What is surprising is that, within a certain range of ratio of on- and off-load periods, the creep in the interrupted case, for a given total time, including the off-load periods, may exceed that for the same time under constant load. Thus the case represented in Fig. 28 is for times exceeding $13^3 = 2200$ sec.* ; the effect of the recovery during the off-load period or the on-load creep more than compensates for the lack of creep during the off-load period.

* The constant n has no connection with the constant n in the work of Andrade and Kennedy previously cited, but is the fraction of the material that has recovered its full β flow.

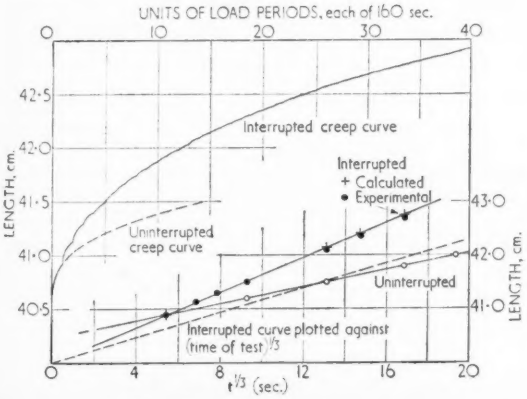


Fig. 28—Effect of intermittent stress

Before very briefly considering the theories that have been evolved, it might be well to say a word on the mechanical behaviour of single crystals of metal. In the first place they are well known to be, in general, exceedingly soft and ductile. Strain takes place by glide on certain crystal planes in certain crystalline directions. With pure metals they begin to deform under tensile stresses of 10–1000 g./sq. mm. or so—about 14–1400 lb./sq. in.—and harden considerably under strain, cubic crystals more so than hexagonal. Thus copper, gold, and silver (face-centred cubic) harden about 80 times (*not* 80%) for 80% glide, a glide which produces a hardening of about 30% only for cadmium. This great softness, compared with ordinary metals, is explained by the well-established assumption that the structure of these crystals is not perfect but contains places of misfit, or ' dislocations ' which travel under small stresses. The passage of a single dislocation leads to the displacement of the crystal to one side of its path relative to that to the other side of one atom spacing : the dislocation can be reflected when it reaches the surface and can travel back, producing another unit displacement, and so on. The hardening that is so marked with cubic crystals I believe to be connected with the rotation of lattice fragments.

Not much has been done on the creep of single crystals under constant stress. Roscoe and I[15] did a few experiments on cadmium, but the most systematic records are those of Cottrell and Aytekin,[19] carried out at constant stress. They found that the flow obeyed the equation $\gamma = \gamma_0 + \beta t^{\frac{1}{3}} + \kappa t$ where γ is the total shear at time t, which is the form which my equation takes when shear, instead of extension, is in question.† They also found that log κ was linear with stress, as in the tensile results. They further stress the point that I have already made, that the wide applicability of the $t^{\frac{1}{3}}$ law shows that the mechanism must be a simple and very general one.

It has been urged that the fact that there is a κ term in the creep of single crystals tends to invalidate the view that in polycrystalline creep the $t^{\frac{1}{3}}$ term is due to glide within the grains and the κ term to move-

* It is clear from the upper curves that, for equal creep represented by length 41·5 cm. in the two cases, the time for the uninterrupted load is about three times that for the other case, which, with off-load period twice that of load period, represents equal times under load.

† There is in this case nothing that corresponds to the increasing length of wire flowing, which gives the exponential form in the tensile case.

ment between the grains. However, in Cottrell and Aytekin's experiments the shear strains were very large compared with anything that takes place in the crystal grains of a polycrystalline metal : for shear strains less than 0·05 (3°) the creep can be fitted by $t^{\frac{1}{3}}$ without any κ term. The κ flow can therefore be attributed to the large glide that takes place on certain slip planes when the glide is very large : no doubt on these planes the crystal structure is broken down and we are practically dealing with crystal-boundary conditions.

When we consider the deformation of polycrystalline metals, one feature is the glide within the crystal grains, with the formation of slip bands, which we put down to the travel of dislocations either from the boundary or from near the boundary, since microscopic observation shows that the slip bands do not always extend right up to the crystal boundary. There are probably strain centres of various degrees of gravity from which dislocations will start under different minimum local shearing stresses : we have seen that the course of β against stress is tolerably represented by :

$$y = C\int_0^x x^2 e^{-x^3} dx$$

The rotation of the glide planes in the grains, experimentally established by experiments of Chalmers and myself on the electrical resistivity of metals during creep, must also play a part. However, until the $t^{\frac{1}{3}}$ law has received a reasonable explanation the variaion of β with stress is unlikely to be satisfactorily solved.

Between two crystal grains is a layer some atoms thick in which the atoms owe, in general, allegiance to neither crystal domain. Flow in these amorphous sheets takes place by the movement past one another, occasioned by thermal fluctuations, of atoms irregularly spaced. The behaviour of the boundaries is reminiscent of that of glasses as far as the effect of temperature is concerned, but, as regards stress, glassses behave as a true viscous liquid, the rate of flow at a given temperature being proportional to the stress. For all Newtonian liquids, including glasses, the activation energy is independent of the stress, which it cannot be for boundary flow in metals. By suitable assumptions concerning the activation energy required for an elementary rearrangement, the logarithmic relation between κ and stress can be deduced (*e.g.*, Dushman, Dunbar, and Huthsteiner[8]).

Attempts have been made to construct a theory of plastic flow on the basis of a suggestion put forward by R. Becker, that elementary increases in strain are produced by increases of local stress due to thermal agitation, the frequency of stress fluctuations which lead to such steps of strain being $\nu = e^{-\frac{A}{kT}}$. This assumption does not lead to any decrease of rate of flow with time, that is, to a transient component of creep. Orowan, to whose constructive criticism the subject owes so much, has modified the theory, but we are still confronted by a relation of the type

$$\frac{d\gamma}{dt} = f(\gamma, \tau, T)$$

where γ is the strain, τ the stress, and T the temperature.[5*] Since metals are seldom, if ever, in thermal equilibrium with their surroundings, such an equation of state cannot be valid. My own approach to the theory, to which I have alluded in discussing the variation of β, does not imply such a relation.

My object has been to persuade you that there are certain simple laws that underlie the study of creep in metals and that a general explanation of many features of the process can be given in terms of the mechanical properties of the crystal grains and of their boundaries. We are, of course, a long way from the knowledge that will enable us to predict the creep behaviour of the complicated alloys that dominate the engineering field today. We do not really understand the mechanism of such processes as recrystallization under strain nor that by which transient flow is effected. I think, however, that we have reached a stage at which we can set out what are the fundamental problems, and to understand the nature of a problem is always an important step towards its solution.

When I was young, Caruso was wont to raise his magnificent voice to remind his audience that *La donna e mobile*. My voice is harsh, but my theme, if less familiar, is equally true, namely that, given suitable conditions *Metalli son mobili*, and I think that we shall find the laws that govern this mobility before we understand the other theme.

Acknowledgments

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Microstructural Changes in the High-Alloy Valve Steel XCR

By B. Cina, B.Sc.

SYNOPSIS

To study the complex diffusion processes involved in the approach to equilibrium of a Cr–Ni–Mo–C valve steel at temperatures up to 1150° C., the microstructural changes produced by heat-treatment at several temperatures have been studied at room temperature by optical microscopy, X-ray diffraction, and hardness determinations, and a correlation found between the results obtained by the three methods.

A STEEL containing 24% of chromium, 5% of nickel, 2·5% of molybdenum, and 0·45% of carbon, such as XCR, may be used for internal-combustion engine valves because it retains a high hardness at temperatures of 500° C. and above.

Its microstructural characteristics, as influenced by variations in the softening and hardening temperatures, have been studied at room temperature by microscopical and X-ray examination and by Vickers hardness testing.

DETAILS OF INVESTIGATION

The material used was in the form of $\frac{3}{8}$-in. dia. hot-rolled bar and had the following composition :

Cast No. 09755

C, %	Si, %	Mn, %	S, %	P, %	Cr, %	Ni, %	Mo, %
0·50	0·86	0·86	0·005	0·025	23·66	4·91	2·67

The as-rolled material was heated for 1 hr. at 1050° or 1150° C., followed by water quenching, to eliminate possible work-hardening effects and to facilitate interpretation of subsequent microstructural changes.

Half-inch long sections of the bar in the two softened conditions were hardened by treatment at 50° intervals between 300–950° C., followed by water quenching. Samples were held for periods of up to one month at temperatures between 475–800° C., and for periods of at least one week at all the other temperatures. Separate samples were used for each hardening treatment.

The hardened specimens were sectioned transversely to the direction of rolling ; the exposed surfaces were linished on a worn No. 2 linishing cloth, and hand polished, ending with 000 emery paper. They were then polished electrolytically, to remove transformation effects introduced by hand-polishing,[2] for 30 sec. at room temperature in a water-cooled mechanically stirred bath containing four parts of methyl alcohol to one of perchloric acid, with a Staybrite steel sheet as cathode. The samples, etched for 40 sec. in Murakami's Reagent (10 g. of potassium ferricyanide, 10 g. of sodium hydroxide, and 100 c.c. of water, used boiling), were examined microscopically and by X-ray diffraction, using the grazing-incidence technique and CoK_α radiation. Vickers diamond-hardness readings were also made under a 30-kg. load.

Microstructure before Hardening

The forging and rolling temperatures of 1200–1000° C. are above the range of σ stability, so that specimens softened at 1050° or 1150° C., followed by water quenching, showed no σ in their microstructures. The latter showed approximately equal proportions of δ-ferrite and austenite with about 10% of the field under observation consisting of undissolved carbides of the type $(Cr,Fe)_{23}C_6$, occurring mainly in the austenitic regions. Typical microstructures of softened samples are shown in Figs. 3 and 4. The very dark particles are the undissolved carbides, stained dark-brown to black by the etching reagent, and the grey angular phase in the matrix is the δ-ferrite, lightly stained in preference to the austenite. The higher softening temperature had little effect on the amount of δ-ferrite present, but made it appear in more compact form. Although the higher temperature would be expected to result in a solution of the carbides to a greater extent in the austenite and to a lesser extent in the ferrite, considerable amounts remained undissolved.

Figure 1 shows the effect of temperature on the hardening characteristics of the alloy after one week at 300–950° C., and also the effect of the different prior-softening temperatures. The hardness of samples softened at 1050° and 1150° C. was 257 and 260 V.D.H. respectively. Maximum hardness, about 450 V.D.H., is obtained at about 750–850° C., with a secondary peak of about 340 V.D.H. at 450–500° C. Figures 2*a* and 2*b* show the rate of hardness increase at temperatures between 475–800°. From 800–650° C., the initial rate of increase in hardness becomes slower as the temperature lessens, but from 600–475° C., this rate becomes faster.

Microstructural Changes Accompanying Hardening

The reactions at the several temperatures corresponded to distinct portions of the curves shown in Fig. 1. The temperature ranges are

(*a*) 950–850° C.
(*b*) 800–650° C.
(*c*) 600–300° C.

and the microstructures will be related to them.

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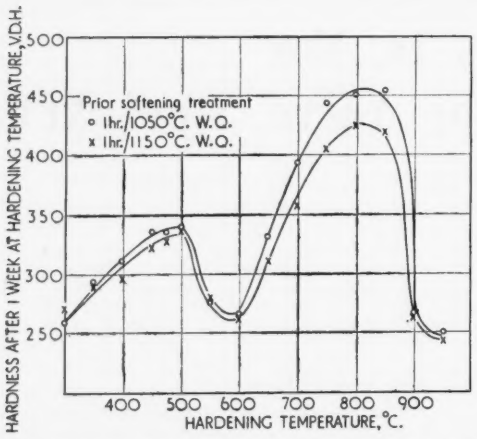

Fig. 1—Hardness/temp. curves for hardening 1050° and 1150° C. prior-softened specimens

Quantitative estimates of the phases observed microscopically were obtained by point counting.[3]

(*a*) *950–850° C.*—No microstructural changes were observed in samples held for one week at 950° C. About 5% σ was detected in samples treated for one week at 900° C. as fairly large particles in place of, or attached to the ends of, the δ-ferrite areas (*see* Fig. 5). The austenitic matrix also showed the presence of a second constituent, acicular in appearance, which proved to be α-ferrite formed by compositional changes during hardening: the matrix becomes unstable and transforms to α-ferrite during subsequent quenching.

Treatment at 850° C. resulted in more rapid formation of σ, which occurs as large particles within the former δ areas (*see* Fig. 6). Less than half the original ferrite was left after one week at this temperature. Two features not observed at 900° C. also appeared:

(1) A carbide precipitate occurring both at the former austenite–δ-ferrite boundaries and just within the former ferritic areas. A similar carbide precipitate was observed by Gilman[1] and by Gilman, Koh, and Zmeskal,[4] the latter noting the phenomenon in the American 19–9*DL* heat-resisting alloy containing 19% of Cr, 9% of Ni, with carbon, molybdenum, tungsten, niobium, and titanium.

(2) A phase between the former austenite–δ-ferrite boundaries and the large σ particles. Since this phase had etching characteristics different from the original δ-ferrite with which it had a sharply defined boundary, it was probably no longer δ-ferrite; as it was sometimes continuous with the original austenite and not always separated from it by a carbide precipitate, it was probably austenite formed by transformation from the δ-ferrite at the hardening temperature. The formation of new austenite during the transformation of δ-ferrite to σ was also observed by Kirkby and Morley in an 18% chromium, 8% nickel, 3% molybdenum, titanium-bearing steel.[5] This new austenite is referred to as γ′ to distinguish it from the original γ. Its presence was later confirmed by correlation of micro and X-ray results.

Alpha-ferrite was again observed in the austenitic zones and in larger amounts than after the same hardening periods at 900° C. The σ particles were located differently in 1050° C. and 1150° C. prior-softened samples. Figure 7 shows the microstructure of the former. In the 1150° C. prior-treated sample, the σ forms almost centrally within the former δ-ferrite areas, but after 1050° C. prior treatment it forms at the extremities of these zones as at 900° C. (*see* Fig. 5).

(*b*) *800–650° C.*—As would be expected from Fig. 2*a*, the microstructures of samples hardened at 750° and 800° C. were very similar for the same hardening period. The rapid hardness increase corresponded to the rate of σ-formation. As at higher hardening temperatures, there was a difference in σ-forming characteristics between samples prior-softened differently, although this was more readily apparent after longer hardening periods. Figures 8 and 9 show the microstructures of samples held for 7 hr. at 800° C. after prior treatments at 1150° and 1050° C. respectively, and Figs. 10 and 11 represent the corresponding microstructures after one week. In Figs. 8 and 9 the large uniformly etched grey areas are δ-ferrite, the original δ boundaries being outlined by a fine carbide precipitate. Within these zones can be detected the unstained γ′ regions, similar in etching characteristics to the original austenitic matrix. The σ in Fig. 8 is unevenly but more deeply stained than the δ-ferrite in which it forms. In Fig. 9, the σ appears adjacent to the δ-ferrite as the brightest constituent in the photo-micrograph. Figures 10 and 11 show the δ-ferrite to have transformed completely to σ and γ′ after one week's treatment, but in the 1050° C. prior-softened sample (Fig. 11) the σ particles are finer and more numerous, in keeping with the more dispersed nature of the original δ-ferrite. Some of the fine dark-etching discrete particles apparent in the original austenite in Fig. 10 are believed also to be σ, and this was even more marked after one month at 800° C. (*see* Fig. 12), where they formed on the crystallographic planes of the austenite.

At 700° C., the rate of σ-formation was slower than at 750° or 800° C. Samples held for 7 hr. at 700° C. showed no σ, but did show that the transformation

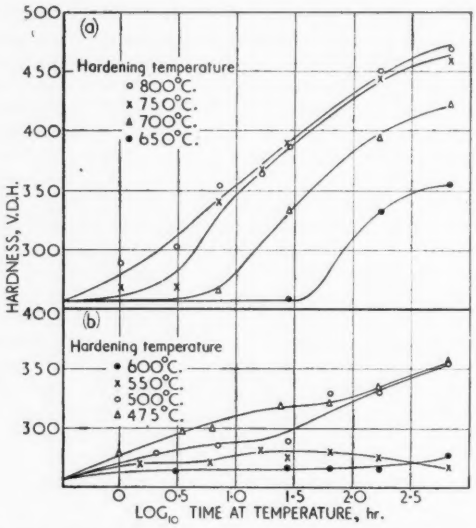

Fig. 2—Rate of hardness increase at temp. 475–800° C.

$\delta \rightarrow \gamma'$ had begun. After 16 hr. at 700° C., an 1150° C. prior-softened sample showed no σ, but there was appreciable γ' (*see* Fig. 13). The transformation began at the δ-ferrite–austenite boundary and proceeded in plate-like form across the δ areas. A small amount of σ appeared after 28 hr. at 700° C., and thereafter increasingly for periods up to one month at this temperature, although 0–5% of δ was still untransformed in both samples after this maximum hardening period. Otherwise, the microstructural features were similar to those obtained after hardening at 750° and 800° C.

At 650° C., a 1050° C. prior-softened sample revealed features similar to, but lesser in extent than, those in an identical sample hardened at 700° C. Thus, after 28 hr. at 650° C. the microstructure was similar to that shown in Fig. 13, although a few fine σ particles were observed within the δ-ferrite areas. After a week at 650° C., the structure was as shown in Fig. 14, with about equal proportions of σ, γ', and untransformed δ-ferrite. There were still some finer σ particles as well as the usual coarser ones.

Although the structures of 1150° and 1050° C. softened samples were similar after only 28 hr. at 650° C., after one week the former showed a slight difference in its σ-forming characteristics, σ occurring as fine but quite discrete particles, in addition to the more normal coarser ones, uniformly distributed over the δ-ferrite areas ; it was also suspected of occurring as plates in the austenite. There was a definite gradation in size between the fine and coarse σ particles. In Fig. 15, γ' and α-ferrite can be observed as in samples hardened at higher temperatures.

(*c*) *600–300° C.*—The microstructural characteristics in the δ-ferrite areas after treatments between 600–450° C. were different from those after treatment at higher temperatures. One week in this range produced a fine precipitate throughout the δ areas (*see* Figs. 16, 17, and 18). With decreasing temperature, finer and less precipitate was observed. The amount of α-ferrite in the austenite matrix, and the carbide precipitate at the austenite–δ-ferrite boundaries, decreased with temperature ; σ could not be detected in any of these samples. The fine precipitate throughout the δ-ferrite areas was not σ. Only after one month at 600° C. was γ' clearly identified in the δ-ferrite. Figure 19 shows the γ' occurring at the edges of the δ-ferrite areas and often in acicular form across the δ-ferrite grains.

Samples prior-softened at 1150° C. and tested for one week at 400°, 350°, and 300° C., showed only a δ–γ boundary phase, which decreased with temperature. This phase was visible only after 400° C. treatment in a 1050° C. prior-softened sample.

Table I

RESULTS OF X-RAY EXAMINATION

Heat-Treatment	1 hr./1050° C., W.Q.	1 hr./1150° C., W.Q.
Ferrite, %	45	45
Austenite, %	45	45

Table II

RESULTS OF POINT COUNTING

Heat-Treatment	1 hr./1050° C., W.Q.	1 hr./1150° C., W.Q.
δ-Ferrite, %	45	45
γ, %	45	45

Effect of Furnace Cooling and Water Quenching from the Softening Temperature

Furnace cooling and water quenching had different effects on the microstructural characteristics observed after hardening. A sample furnace-cooled at 200°/hr. from 1050° C. had a microstructure very similar to that of a 1050° C. W.Q. sample, save that the former contained < 1% of σ as discrete particles at the extremities of the δ-ferrite areas. There was a suggestion of α-ferrite in the austenite matrix (*see* Fig. 20).

The microstructure of a 1050° C. F.C. sample suggested, after the initial stages of hardening, that the σ formed in more uniform distribution round the δ-ferrite areas, and less dispersed within them than in a 1050° C. W.Q. sample. There was no carbide precipitate at the former austenite–δ-ferrite boundaries in a F.C. sample. Figures 21 and 22 show these features.

Results of X-Ray Examination

After quenching, the samples consisted of varying proportions of δ and α-ferrite, original γ and new γ', σ, and undissolved and precipitated $(Cr,Fe)_{23}C_6$. Block specimens being used for the X-ray examination, the grazing-incidence technique did not distinguish between δ and α-ferrite, between original γ and γ', or between undissolved and precipitated carbides, so that the intensities of the ferrite, austenite, and carbide spectra represented the combined effect of their constituents. A quantitative estimate of the ferrite and austenite phases respectively was obtained by comparing their relative intensities in any one X-ray photograph with those of standard compacts of annealed filings of a fully ferritic and a fully austenitic steel mixed in known proportions, and checked by photometer measurements of the intensities of the two spectra.

Table III

RESULTS OF X-RAY EXAMINATION

Hardening Treatment	7 hr./700° C., W.Q.		28 hr./700° C., W.Q.		1 week/700° C., W.Q.		1 month/700° C., W.Q.	
Softening Temp., ° C.	1050	1150	1050	1150	1050	1150	1050	1150
σ, %	0	0	5–10	0	15–20	15	15–20	15
$(\delta + \alpha + \alpha')$, %	50	50	45	50	40	45	50	45
$(\gamma + \gamma')$, %	40	40	35	40–45	30	35	25	30

Table IV

RESULTS OF POINT COUNTING

Hardening Treatment	7 hr./700° C., W.Q.		28 hr./700° C., W.Q.		1 week/700° C., W.Q.		1 month/700° C., W.Q.	
Softening Temp., ° C.	1050	1150	1050	1150	1050	1150	1050	1150
σ, %	1–2	0	10–15	Trace	15–20	10	20–25	20
δ, %	40	30	20	10	5	5–10	0–5	0–5

Every sample was X-rayed and its σ, total ferrite, and total austenite content estimated, but only some of these measurements need be recorded (*see* Tables I, III, and VI). These are considered with estimates obtained by point counting of the remaining δ-ferrite, and the γ' (formed at the hardening temperature) and σ phases (*see* Tables II, IV, and VII).

Correlation between the Results of Micro and X-Ray Examination

Both methods of phase estimation give similar results for the percentage of σ present. The results from both methods can also be combined to confirm the presence of such phases as γ', α-ferrite, and α'-ferrite (believed to form from γ' on quenching, as α forms from γ). This combined method of phase identification and estimation is as follows :

(1) By subtracting the percentage of δ-ferrite (obtained by point counting) from the $(\delta + \alpha + \alpha')$ by X-ray, the percentage of $(\alpha + \alpha')$ ferrite is obtained.

(2) The α-ferrite forms only in the original γ areas, which are constant and known (by point counting and X-ray). The α' is assumed to form in the γ'. If it is assumed that half the γ' forms α', then if the estimate of $(\alpha + \alpha')$ ferrite is subtracted from the (original $\gamma + \frac{1}{2}\gamma'$), the original γ remaining is obtained. The amount of γ' formed at temperature is obtained by subtracting (remaining $\delta + \sigma$) from original δ. If the original γ remaining is subtracted from $(\gamma + \gamma')$ the percentage of γ' remaining is obtained.

This gives a fairly accurate estimation of the σ phase, the untransformed δ-ferrite, $(\alpha + \alpha')$ ferrite, and γ' (formed at temperature), and approximate percentages of original γ and new γ' left. The combined results are listed in Tables V and VIII.

The data in Tables V and VIII show that for the same prior-softening temperature and with time, there is a progressive increase in the amount of σ formed and a decrease in the amount of δ-ferrite remaining. The total percentage of δ-ferrite remaining plus σ formed was, however, for every case less than 45%, the amount of δ-ferrite originally present. This deficit was evidence for the existence of γ', which was identified in the microstructure and the presence of which has been noted by others[1, 4, 5] in similar steels. Assuming the original δ-ferrite areas to consist of remanent δ-ferrite, σ, and γ', the discrepancy between the estimation of δ-ferrite by micro-examination and total ferrite determined by X-ray suggests a new ferrite phase. This was the α and α'-ferrite observed in the γ and γ' areas respectively, and detected magnetically even when no δ-ferrite was left. The presence of α-ferrite has also been noted by Gilman.[1] By a refinement of the calculations in Tables V and VIII made on the assumption that $\frac{1}{2}\gamma'$ transformed to α' on quenching, an estimate of the original γ untransformed after quenching, and also of the untransformed γ' can be obtained. Tables V and VIII show that for both softened samples the γ' formed at the hardening temperature increases with time, but suggest that it was less stable in 1150° C. than 1050° C. prior-treated material. The stability of the original γ decreased with time, but it tended to be slightly more stable at 700° than at 800° C. The tables show a more rapid σ-formation at 800° than at 700° C., but there is no significant difference in the rate of γ'-formation at 700° or 800° C. for the same prior-softening temperature. The tables show the more rapid γ'-formation in 1150° C. softened samples.

X-Ray Results after Hardening above 800° C. and below 700° C.

X-ray results on samples hardened for one week at 900° C. confirmed the small amounts (about 5%) of σ and α-ferrite observed in their microstructures ; σ was also confirmed in samples hardened at 850° C. After one week at this temperature, an 1150° C. prior-softened sample contained more $(\alpha + \alpha')$ ferrite and

Table V

COMBINED RESULTS OF TABLES III AND IV

Hardening Treatment	7 hr./700° C., W.Q.		28 hr./700° C., W.Q.		1 week/700° C., W.Q.		1 month/700° C., W.Q.	
Softening Temp., ° C.	1050	1150	1050	1150	1050	1150	1050	1150
σ, %	1–2	0	10–15	Trace	15–20	10	20–25	20
Remaining δ, %	40	30	20	10	5	5–10	0–5	0–5
γ' (at temp.), %	3–4	15	10–15	35	20–25	25–30	20	20–25
$(\alpha + \alpha')$, %	10	20	25	40	35	35–40	45–50	40–45
Remaining γ, %	35	30–35	25	20	20	20	5–10	20–25
Remaining γ', %	~5	5–10	10	20–25	10	15	15–20	5–10

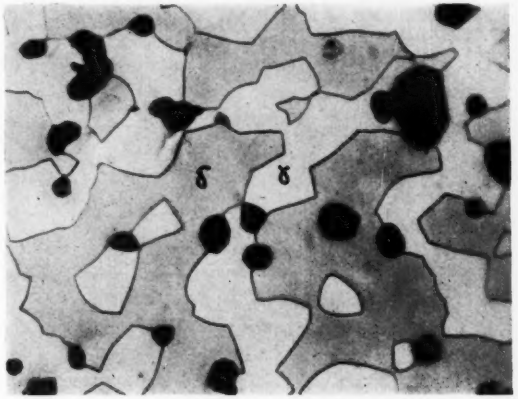

Fig. 3—1 hr. at 1050° C., W.Q.

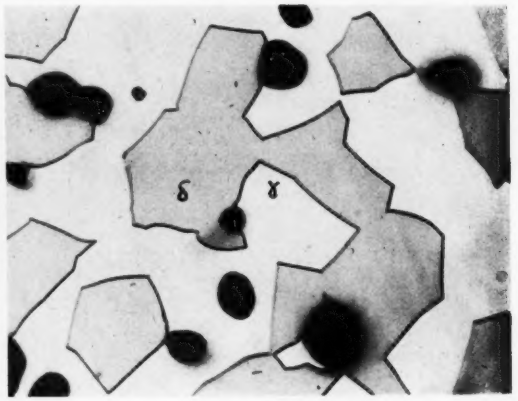

Fig. 4—1 hr. at 1150° C., W.Q.

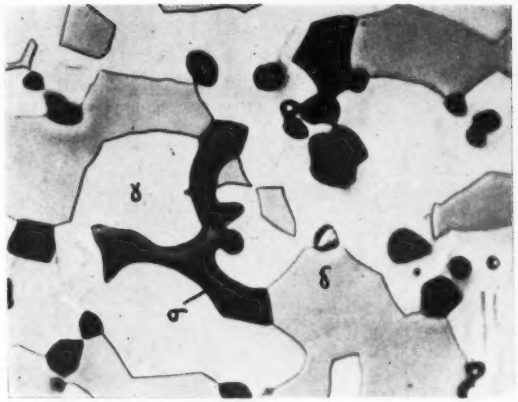

Fig. 5—1050° C., W.Q. — 1 week at 900° C., W.Q.

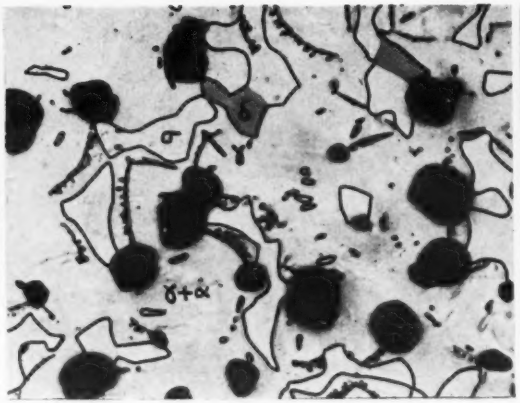

Fig. 6—1150° C., W.Q. — 1 week at 850° C., W.Q.

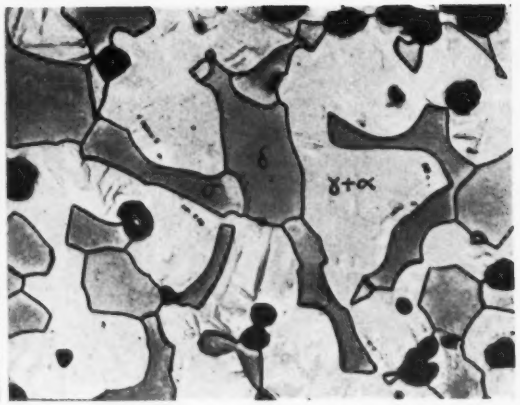

Fig. 7—1050° C., W.Q. — 1 week at 850° C., W.Q.

Figs. 3-7—Etched with Murakami's Reagent

[Cont'd from p. 232]

Fig. 8—1150° C., W.Q. + 7 hr. at 800° C., W.Q.

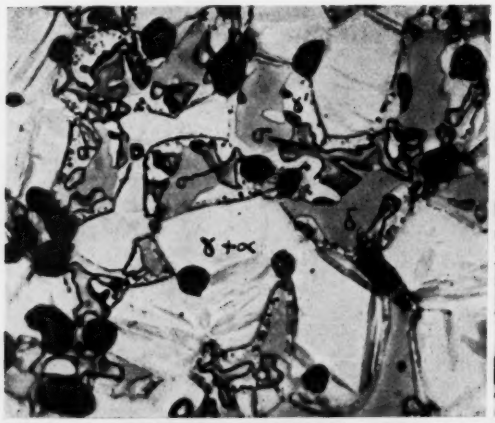

Fig. 9—1050° C., W.Q. + 7 hr. at 800° C., W.Q.

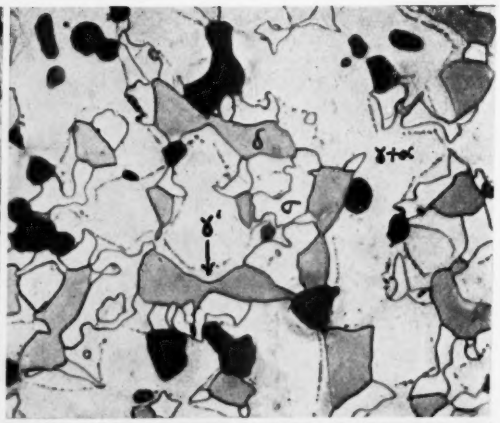

Fig. 10—1150° C., W.Q. + 1 week at 800° C., W.Q.

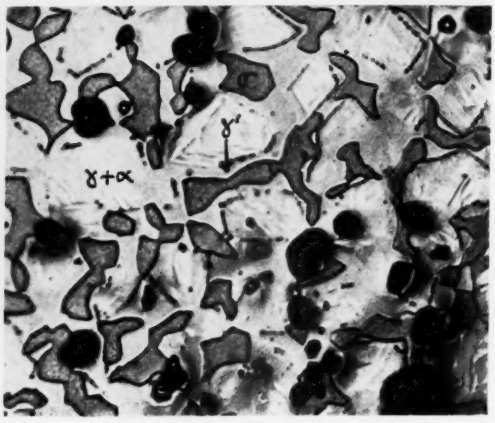

Fig. 11—1050° C., W.Q. + 1 week at 800° C., W.Q.

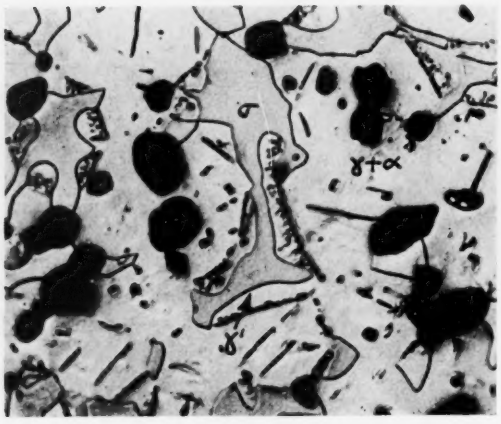

Fig. 12—1150° C., W.Q. + 1 month at 800° C., W.Q.

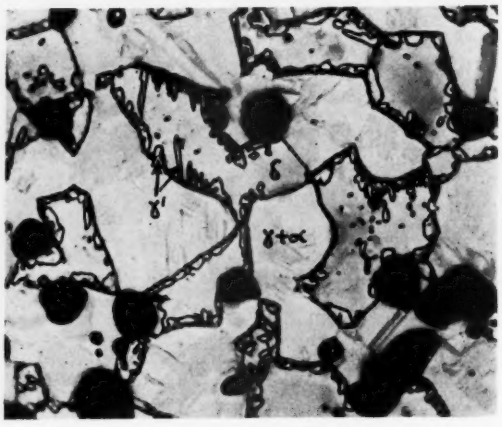

Fig. 13—1150° C., W.Q. + 16 hr. at 700° C.

Figs. 8-13—Etched with Murakami's Reagent × 1500

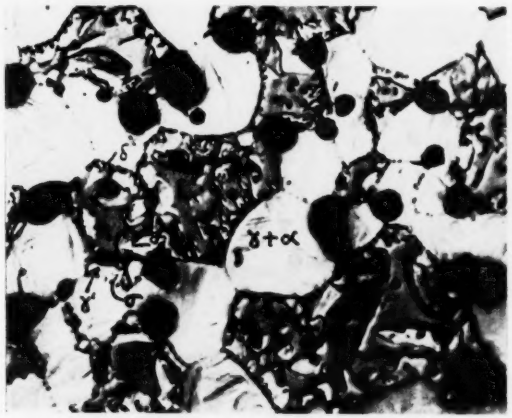

Fig. 14—1050° C., W.Q. + 1 week at 650° C.

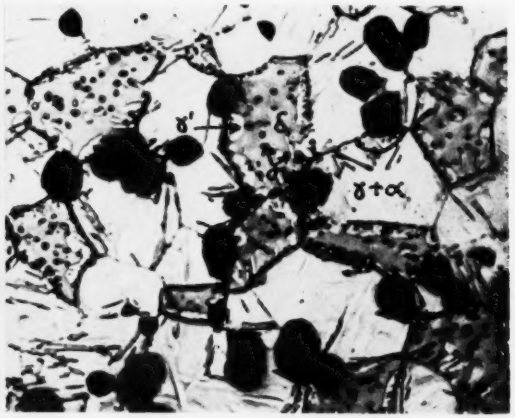

Fig. 15—1150° C., W.Q. + 1 week at 650° C., W.Q.

Fig. 16—1150° C., W.Q. + 1 week at 600° C.

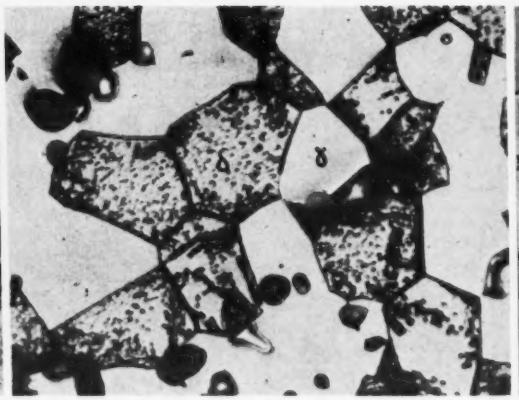

Fig. 17—1150° C., W.Q. + 1 week at 475° C., W.Q.

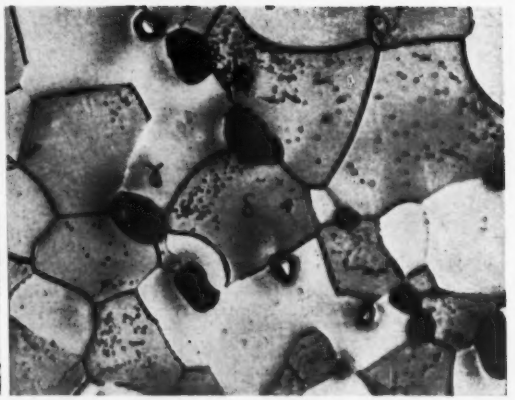

Fig. 18—1150° C., W.Q. + 1 week at 450° C.

Figs. 14, 15 and 16—Etched with Murakami's Reagent. Figs. 17 and 18—Etched electrolytically with 10% oxalic acid (aq.) 1500

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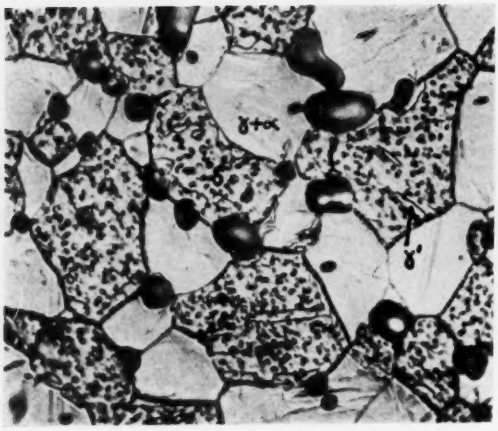

Fig. 19—1150° C., W.Q. + 1 month at 600° C., W.Q.

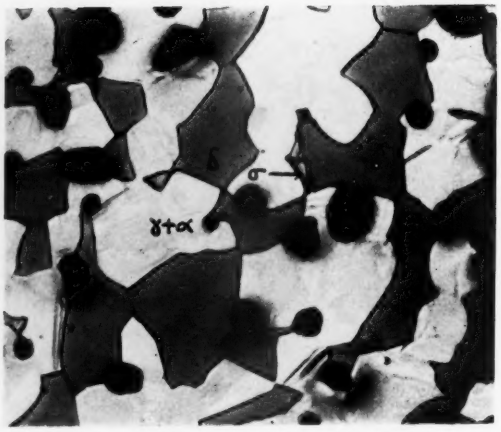

Fig. 20—1 hr. at 1050° C., furnace cooled to room temperature

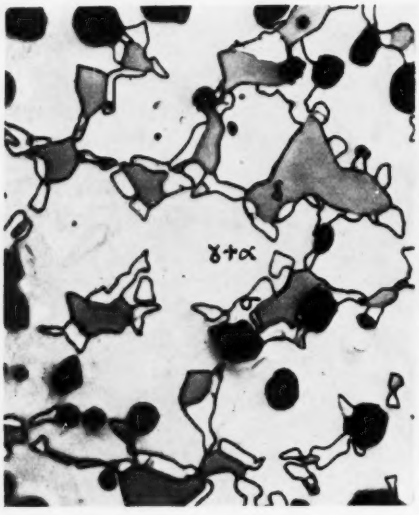

Fig. 21—1050° C., F.C. + 7 hr. at 750° C., W.Q.

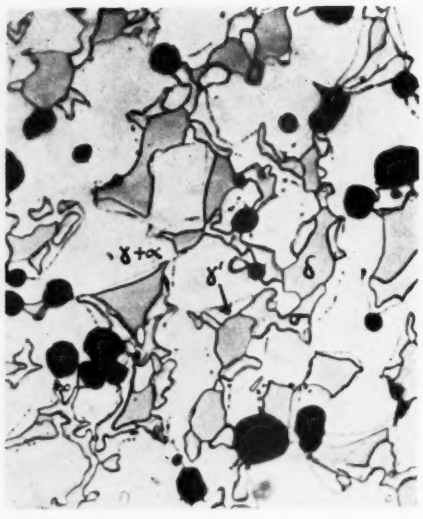

Fig. 22—1050° C., W.Q. + 7 hr. at 750° C., W.Q.

Fig. 19—Etched electrolytically with 10% oxalic acid (aq.). Figs. 20, 21 and 22—Etched with Murakami's Reagent 1500

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Table VI
RESULTS OF X-RAY EXAMINATION

Hardening Treatment	7 hr./800° C., W.Q.		28 hr./800° C., W.Q.		1 week/800° C., W.Q.		1 month/800° C., W.Q.	
Softening Temp., ° C.	1050	1150	1050	1150	1050	1150	1050	1150
σ, %	5–10	5–10	10	10	15–20	20	15–20	15–20
$(\delta + \alpha + \alpha')$, %	50	40	45	45	40	40	50	55
$(\gamma + \gamma')$, %	30	40	35	35	30	30	25	15

more γ' than a 1050° C. prior-softened one, confirming the results obtained at lower temperatures. Samples hardened at 650° C. showed a slower rate of σ-formation and less decomposition of the γ than at 700° C., and confirmed the tendencies observed at this temperature. No σ could be detected by X-ray in samples hardened for one week at 300–450° C. or after one month at 475–600° C. After quenching from 600° and 550° C. there were indications of the formation of α-ferrite, but not in 500–300° C. hardened samples. Since α-ferrite was detected metallographically in a 500° C. hardened sample, the increase in ferrite content through α-formation might have been counterbalanced by a decrease in δ-content, possibly due to formation of γ'.

DISCUSSION

The reactions in the δ-ferrite and austenite regions of the alloy during hardening can best be understood in relation to the approach to equilibrium at the several temperatures.

Before considering the reactions in the δ and γ, the compositions of these two phases after the softening treatments at 1050° or 1150° C. must be known. The fact that they are simultaneously stable at 1050° or 1150° C. indicates a segregation of alloying elements between them such that δ-ferrite is enriched with δ-forming elements such as chromium, molybdenum, and silicon, and the γ with γ-forming elements such as carbon, nickel, and manganese. Previous work in this laboratory[5] has proved the δ-ferrite areas in a duplex 18% chromium, 8% nickel, 3% molybdenum, titanium-bearing alloy to be richer in chromium than the adjacent austenitic zones, and a similar relationship probably exists in XCR. This would further be indicated by the preferential σ-formation in this constituent, although this could be related to the believed greater similarity between the δ-ferrite and σ lattices than between γ and σ, and consequently easier σ-formation from the ferrite.[4] Evidence for this greater similarity between body-centred cubic δ-ferrite and σ might be found in the recent proposal,[6] now confirmed,[15] of a tetragonal structure for σ.

The segregation of the carbon was indicated by the undissolved carbides being distributed preferentially in the austenite areas, and by the mode of carbide precipitation at the former γ–δ boundaries. Further proof was obtained from the microstructural examination of a modified XCR alloy containing only 0·06% of carbon. The full composition of this alloy was as follows :

Cast No. G.2532

C, %	Si, %	Mn, %	S, %	P, %	Cr, %	Ni, %	Mo, %
0·06	0·58	0·33	n.d.	n.d.	24·83	5·53	2·85

Table VII
RESULTS OF POINT COUNTING

Hardening Treatment	7 hr./800° C., W.Q.		28 hr./800° C., W.Q.		1 week/800° C., W.Q.		1 month/800° C., W.Q.	
Softening Temp., ° C.	1050	1150	1050	1150	1050	1150	1050	1150
σ, %	10–15	5–10	10–15	15	20–25	20–25	25	20
δ, %	25–30	15–20	15–20	5	0	0	0	0

Table VIII
COMBINED RESULTS OF TABLES VI AND VII

Hardening Treatment	7 hr./800° C., W.Q.		28 hr./800° C., W.Q.		1 week/800° C., W.Q.		1 month/800° C., W.Q.	
Softening Temp., ° C.	1050	1150	1050	1150	1050	1150	1050	1150
σ, %	10–15	5–10	10–15	15	20–25	20–25	25	20
Remaining δ, %	25–30	15–20	15–20	5	0	0	0	0
γ' (at temp.), %	0–10	15–25	10–20	25	20–25	20–25	20	25
$(\alpha + \alpha')$, %	20–25	20–25	25–30	40	40	40	50	55
Remaining γ, %	25	30–35	25	15–20	15	15	5	0–5
Remaining γ', %	5	5–10	10	15–20	15	15	20	10–15

A forged sample of cast G.2532 in the 1050° C. softened condition showed its undissolved carbides to be segregated in the γ areas. This sample contained 65% of δ-ferrite and only 35% of γ. Since it showed a few carbides out of solution after 1 hr. at 1050° C., W.Q., its γ must have contained $< 0{\cdot}06\%$ of carbon in solution. The difference in δ-ferrite contents between the two casts can therefore be attributed to the greater amount of chromium available to enrich and form δ in cast G.2532 because of the lesser amount required to combine with the excess carbon.

An estimate of the actual carbon in solution in the normal XCR alloy gave a value of $0{\cdot}2\%$, derived from the nominal analysis of the alloy, the carbide undissolved being taken at an average value of $7{\cdot}38\%$ by volume, derived by point counting, and from the density* of $(Cr)_{23}C_6$ being calculated as 5·5 (actually 5·508). This $0{\cdot}2\%$ of carbon would be dissolved mainly in the γ and to a lesser extent in the δ-ferrite. Calculations show that $4{\cdot}96$ wt.-% of chromium is combined with the excess carbon as undissolved $Cr_{23}C_6$ in the normal XCR alloy. Since the chromium in $Cr_{23}C_6$ can be replaced by iron to the extent of about 30%,[7] the chromium held in the carbide will be between $3{\cdot}5\%$ and 5%. The apparent higher solubility of carbon in the XCR alloy may be explained by the fact that its γ would contain less chromium than that of G.2532 because of the $3{\cdot}5$–$5{\cdot}0\%$ of chromium out of solution as carbide in the former. Work carried out in this laboratory[8] has shown that in a series of fully austenitic steels of 20% nickel content, the solubility of carbon decreased as the chromium content increased from 10–25%.

Reactions in the δ-Ferrite

650–1150° C.—At temperatures of 650–900° C. two main reactions occur: (1) δ-ferrite → σ, and (2) δ-ferrite → γ′. (The presence of undissolved carbides will be assumed throughout.) Their rate and extent depend on the hardening and prior-softening temperatures. Although γ and δ-ferrite were the only phases found after one week at 950° C., about 5% of σ was found to be stable at 900° C. Gilman[1] found σ within 16 hr. at 940° C. This apparently readier σ-formation in his alloy may be associated with its lower carbon content and consequent greater availability of chromium than in the cast used in this study. Oliver,[9] in a survey of the literature on the σ phase in stainless steels, quotes a ceiling temperature of about 927° C. for the σ phase in iron–chromium alloys to which nickel has been added in moderate amounts. The results at 900° C. indicate that δ-ferrite, γ, and σ are all stable at this temperature. At 700–850° C., only σ and austenite appear to be stable. On the basis of the present work, the reactions occurring in the δ-ferrite may be explained as follows:

> In the early stages of hardening, the chromium in the δ-ferrite zones diffuses inwards where eventually it concentrates so as to permit the formation of σ. Before, or at the same time as this σ-formation, the outer chromium-depleted δ-ferrite regions may transform to γ′. Eventually the entire outer regions of the δ-ferrite have transformed to γ′, and the inner regions to σ.

The higher the softening temperature, the lower is the chromium content required for stabilizing the δ-ferrite, the excess chromium diffusing into the austenite. In some alloys such as the 18% chromium, 8% nickel, 3% molybdenum type, this increases the δ-ferrite content, but in XCR the amount of δ-ferrite is not significantly changed by softening at 1150° C. instead of 1050° C. The reduction of its chromium content by the higher temperature is shown by the more rapid transformation of this δ to γ′ at the subsequent hardening temperatures, and by the slower rate of σ-formation. The latter reaction would also be affected by the smaller volume of δ-ferrite left to form σ, and the greater difficulty of its formation from γ′.

Furnace cooling at 200° C./hr. as opposed to water quenching from the softening temperature caused the σ to form more uniformly round the outer regions of the δ-ferrite areas in the early stages of hardening. This can be explained by the more gradual approach to equilibrium of prior F.C. samples. During furnace cooling, and especially at higher temperatures, where diffusion of alloying elements would be most rapid, the δ-ferrite areas decrease in amount because their stability decreases with temperature. This is effected by a series of reactions and diffusion processes similar to those obtained by isothermal treatment in the same temperature range, but, the decrease in temperature being gradual, the approach to equilibrium can occur more uniformly, as revealed by the latter mode of σ-formation.

600–300° C.—There is no evidence to confirm the inference that since the σ particles appeared in finer form as the hardening temperature decreased from 900° to 650° C., the precipitate observed in the δ-ferrite in decreasing amount and size between 600° and 300° C. was also σ. X-ray grazing-incidence techniques of 1% sensitivity failed to reveal any σ and it can be seen, especially from Figs. 16 and 19, that $\gg 1\%$ of precipitate was present, point counting giving values of 12 and 16% respectively. Variations in the polishing and etching techniques used before X-ray examination were also ineffective in this respect.

There was evidence that the particles were wholly or largely γ′. The γ′ visible after hardening behaved like the σ, in that with decreasing temperature it appeared in finer and more dispersed form, in keeping with the characteristics of the particles formed between 600° and 300° C. More positive evidence for the particles being γ′ is afforded by comparing Figs. 16 and 19. In the latter, distinct γ′ particles can be observed in plate-like form across, and as distinct pools at, the edge of the δ-ferrite areas. Some of the finer particles are coalescing so that there is a definite gradation of particle size from the largest-sized in Fig. 16 to platelets up to 15 mm. (at × 1500) long. These platelets did not stain in Murakami's Reagent but had the etching characteristics associated with γ′.

Reactions in the γ′

The γ′ formed by transformation from the δ-ferrite at the hardening temperature as a step in the approach to equilibrium, at least initially, has a composition

* Calculated from the fundamental equation suggested by Foote and Jette,[13] and from unit cell and lattice dimensions data given by Westgren.[14]

different from the remaining δ-ferrite and from the original γ. Since σ is stable at this temperature (at least at 650–900° C.) its formation requires diffusion of chromium, so that local depletion of the latter in the δ-ferrite facilitates the transformation $\delta \rightarrow \gamma'$. Since the alloy has been brought abruptly from 1050° or 1150° C. to a much lower temperature, the equilibrium alloy content of the several phases stable at the new temperature will not be attained immediately. If an arbitrary chromium content is assumed in the δ-ferrite and γ at 1050° C. of 25% and 15% respectively, and the equilibrium chromium content of the γ and γ′ phases at 750° C. is assumed to be 10%, then in the initial stages of hardening at 750° C., when the chromium content of the δ-ferrite has been reduced by diffusion inwards to some intermediate value, say 20%, the latter may be insufficient to stabilize the δ-ferrite, and consequent transformation to γ′ occurs. The γ′ at this instant is richer in ferrite-forming and poorer in austenite-forming elements than the original γ, so that on quenching the γ′ would further transform to α′-ferrite to a greater extent than the original γ because of its ferrite-promoting elements. If the alloy is held longer at the hardening temperature, diffusion of carbon from the carbon-rich γ to the carbon-poor γ′ occurs, as suggested by Gilman, Koh, and Zmeskal,[4] reducing the stability of the γ on quenching relative to that of γ′. The fact that chromium carbide was precipitated at the γ–γ′ boundaries and within the γ′ may be evidence of the higher chromium content of the γ′, betokening its lower solubility of carbon. There is no carbide precipitate after hardening a prior F.C. sample because the outer regions of the δ-ferrite have already lost some of their chromium content by diffusion inwards during furnace cooling. Therefore, each amount of γ′ formed has time to allow the alloying elements (with which it was enriched with respect to that in the original γ) to diffuse into the γ, and a similar but counter-diffusion occurs from γ to γ′. Carbon diffusing from γ to γ′ will not meet a higher chromium content and so no precipitation need occur.

The carbide precipitate at the γ–δ boundaries after hardening is due to the lower solubility of carbon in γ at the hardening than at the softening temperatures. Grain boundaries offer the most convenient sites for this precipitation in prior-softened material; γ–δ boundaries would be preferred to those in the γ itself because of the greater amount of chromium available in the δ to precipitate the carbon as $(Cr,Fe)_{23}C_6$. Once this precipitation had begun, a concentration gradient of carbon content would be established in the γ, ensuring further diffusion of carbon to the γ–δ boundaries. The precipitation would cause local depletions of chromium at the edges of the δ-ferrite areas, facilitating the transformation $\delta \rightarrow \gamma'$.

Stability of γ and γ′

Both micro and X-ray work have shown that σ can eventually form, generally to a small extent, from γ and γ′; perhaps more rapidly from γ′ on account of its higher initial content of chromium, and presumably also of molybdenum and silicon, all of which promote σ-formation in both austenite and ferrite. Both methods of examination also indicated that on quenching both γ and γ′ transformed to some extent to α-ferrite, confirming the observations of Gilman[1] that on slow cooling the transformation occurs isothermally at about 27° C., with the exact temperature depending on the elevated temperature history. The acicular nature of this transformation product, and its occurrence at a low temperature, at which diffusion rates would be very slow, suggests that the reaction was of the diffusionless martensitic type corresponding to the distorted body-centred cubic α_2 phase observed by Rees, Burns, and Cook[10] in pure iron–nickel–chromium alloys, and to a similar phase commonly observed after tempering commercial 18% chromium–8% nickel alloys between about 450–850° C. The author[11] has recently shown that in the latter alloy the ferrite phase does not form at the tempering temperature but only on cooling below about 300° C. In the latter case, the instability of the austenite on quenching is caused by its carbon content precipitating as $(Cr,Fe)_{23}C_6$ at the tempering temperature.

A similar mechanism is suggested for the $\gamma \rightarrow \alpha$ and $\gamma' \rightarrow \alpha'$ transformations observed in XCR. Deprived of their carbon contents, these γ and γ′ phases will have lost one of their main stabilizing elements. Since the small nickel content of the alloy must now be distributed throughout a larger volume $(\gamma + \gamma')$, its effective stabilizing influence will be reduced, and, owing to the pick-up of chromium by the austenite from the δ, there will be three factors to favour the transformation of the austenite to α-ferrite phases.

The presence of α′ was confirmed in two ways. Firstly, in samples where all the δ-ferrite had been converted to σ and γ′, X-ray detected > 45% of ferrite. Since the original 45% of γ could form only 45% of α, the excess ferrite must have been α′. In a sample given 1150° C., W.Q. + 1 month at 800° C., W.Q., no δ-ferrite was left, but 55% of $(\alpha + \alpha')$ ferrite was detected by X-ray. As it was further calculated that up to 5% of the original austenite was untransformed, the amount of α-ferrite could have been only 40–45%, so that the balance of 10–15% must have been α′. Less reliable supporting evidence for the presence of α′ was obtained from microscopic observation.

In Tables V and VIII, the assumption that $\frac{1}{2}\gamma'$ transformed to α′ on quenching was made because:

(*a*) It was known that such a transformation occurred, and

(*b*) As it was known that for certain conditions only part of the γ transformed to α, it was considered likely that γ′ would also only partially transform to α′.

Since the amount of γ′ present at temperature varied from 0–25%, which is only up to $\frac{1}{2}\gamma$, a figure of $\frac{1}{2}\gamma'$, even if not exact, would give a maximum error of 12·5% when no α′ was actually present, and probably $\ll 12{\cdot}5\%$ when it was, since only after one month at certain temperatures was there as much as 25% of γ′ formed.

Correlation between Microstructure and Hardness

Figure 1 showed the effect of the hardening temperature on the hardness obtained after one week. The hardness value obtained for any hardening temperature between 650–950° C. can be related directly to the amount of σ present after treatment. This is

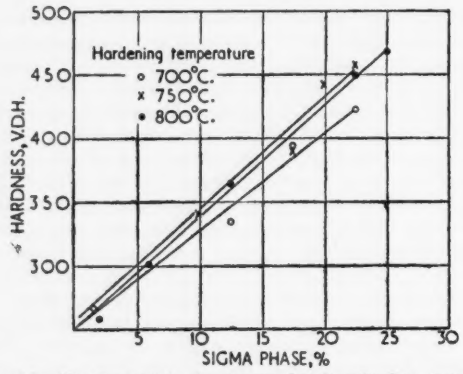

Fig. 23—Hardness/% of σ curve for hardening temps. 700°, 750°, and 800° C.

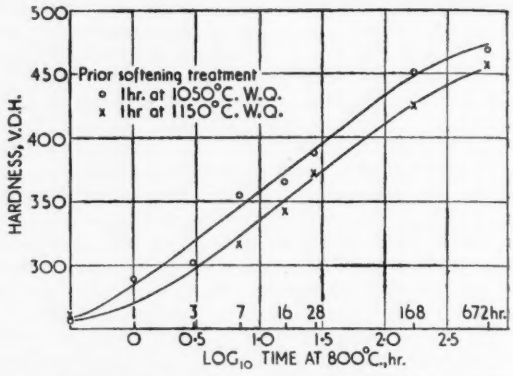

Fig. 24—Rate of hardness increase at 800° C. for 1050° and 1150° C. prior-softened specimens

shown in Fig. 23 by an almost linear relationship between hardness and percentage of σ for temperatures of 700°, 750°, and 800° C. This relationship does not agree with that reported by Gilman,[1] who found that a rapid hardness increase in samples treated at 760° and 816° C. was not obtained until about 15% of σ had been formed. The disagreement may be explained by the fact that Gilman's samples were hardened in the as-rolled condition, while those in the present work were softened before hardening. In the early stages of treatment at 760° and 816° C. in the American[1] work a hardening due to σ-formation may have been masked by a superimposed softening due to recrystallization or the relief of stresses resulting from rolling. Treatments of Gilman's as-rolled material for periods of less than 1 hr. (the minimum time quoted in his Fig. 18) might indicate such softening before σ-formation. He shows later that samples annealed for 3 hr. at temperatures between about 920–1149° C. were, in fact, softer than as-rolled material, which confirms the previous suggestion.

The consistently lower hardness obtained in samples prior-softened at 1150° C. as compared with 1050° C. has already been indicated in Fig. 1 and is further illustrated in Fig. 24. These show that the effect is observed at all the hardening temperatures used, and at all stages of hardening at one temperature.

The lower hardness resulting from 1150° C. softened samples may be attributed either to the σ being present in smaller amounts because of its slower formation, or to the mixed-phase hardening factor described by Gilman,[1] since the σ particles were smaller and more numerous in 1050° C. than in 1150° C. prior-softened samples.

Although mixed-phase hardening may be a factor in samples prior-treated at different softening temperatures, it is not during the various stages of σ-formation in samples prior-softened at the same temperature.

In regard to the secondary hardness peak in samples treated between 300° and 600° C., the presence of σ could not be detected by X-ray grazing-incidence techniques of sensitivity increased to detection of 1% of the phase present. It is significant that this is similar to the 475° C. embrittlement in certain chromium irons. The curve for 475° C. hardening in Fig. 2*b* shows the rate and therefore probably the mode of hardening to be different from those observed at 650–800° C., while the curve for 550° C. suggests an age-hardening effect with a final over-ageing period. An investigation[12] of this 475° C. embrittlement is in progress and the results should shortly be available for publication.

CONCLUSIONS

As quenched from softening temperatures of 1050° or 1150° C. the alloy XCR consists of equal proportions of δ-ferrite and austenite, with undissolved chromium carbides occurring mainly in the austenitic zones. Hardening at temperatures between 650–900° C. causes the σ phase to form primarily from the δ-ferrite, and a linear relationship has been found between hardness and the percentage of σ. Maximum hardness is attained between 750° and 850° C. The formation of σ is accompanied by complex diffusion processes leading to the transformation of δ-ferrite to austenite (γ′) at the hardening temperature, and to the transformation of the original and new austenitic phases to α-ferrite on quenching. The prior-softening temperature determined the rate of σ-formation, the rate of transformation δ-ferrite → γ′, and the associated diffusion processes and reactions. A secondary hardening effect was observed at 300–600° C., at a maximum between 475–500° C., although σ could not be detected in any of these samples. The mode of this 475° C. hardening was different from that observed at 650–900° C., and an over-ageing effect was found at 550° C.

Acknowledgments

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A Note on the Formation of Undercooled Graphite in High-Purity Iron–Carbon–Silicon Alloys

By W. S. Owen, Ph.D., M.Eng., A.I.M., and B. G. Street, Ph.D., B.Eng.

SYNOPSIS

It has been shown that the formation of undercooled graphite in vacuum-melted high-purity iron–carbon–silicon alloys is a result of the decomposition of an undercooled austenite–carbide complex. This is in agreement with the description given by Eash of the solidification of commercial cast irons which had been specially treated to produce undercooled graphite. X-ray diffraction examination has shown that the undercooled carbide is cementite. In general terms, an explanation of the phenomena is suggested.

HIGH-PURITY iron–carbon–silicon alloys, melted and cooled *in vacuo*, solidify with a eutectic graphite structure usually described as undercooled (A.S.T.M. Type *D*). The conditions that produce undercooled graphite in cast irons, together with earlier theories advanced to explain this structure, have been reviewed by Morrogh and Williams.[1] They showed that irons having this structure possess a fine acicular carbide eutectic on solidification, which subsequently decomposes (in agreement with Eash's[2] work). The breakdown of this carbide is extremely rapid and may even be proceeding before the whole of the eutectic is solid.

If the conclusions drawn by Morrogh and Williams are extended to high-purity alloys melted *in vacuo*, it can be seen that these alloys will solidify in accordance with a metastable carbide system rather than the equilibrium graphite system. As this assumption is of considerable importance in the interpretation of thermal analysis data, it was considered necessary to test it experimentally.

EXPERIMENTAL WORK

The alloys used were prepared from Hilger iron *JM*845 (major impurity 0·007% of Ni), 99·92% silicon metal, and graphite having less than 0·07% of ash. Ingots weighing approximately 8 g. were melted, under a pressure continuously less than 10^{-3} mm. of Hg, in recrystallized alumina crucibles. A Pt/Pt–10% Rh thermocouple in an alumina sheath was immersed in the melt, and the temperature was measured using a sensitive null-deflection potentiometer. Specimens could be cooled at a controlled rate, or quenched through a stream of argon into cold water. It is hoped to give a full description of the apparatus elsewhere.

Alloys allowed to cool slowly to room temperature had undercooled graphite structures. After quenching part way through the eutectic arrest, the hypo-eutectic alloys had a structure consisting of primary dendrites of austenite–martensite in a groundmass that was partly undercooled graphite and partly the acicular carbide eutectic structure (*see* Fig. 1). In every specimen examined, the amount of acicular carbide present was much greater than that which would be expected to form during the rapid cooling of the liquid remaining after the incomplete eutectic solidification. For example, a normal 3% C, 2% Si alloy, held in the molten state for 2 hr. in a vacuum of 3×10^{-4} mm. of Hg and then slowly cooled, had a eutectic arrest lasting 110 sec. When quenched through argon into water, 20 sec. after the start of the arrest, the only graphite which could be found was a very small amount along one edge of the specimen.

This and similar observations, verified analytically, demonstrated that the results obtained by Morrogh

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and Williams on alloys containing titanium and melted in air could be reproduced in high-purity alloys melted *in vacuo*.

When annealed at temperatures below the solidus, the acicular carbide structure breaks down to give spheroidal or nodular graphite structures.[1] Figure 2 shows the structure of a hypo-eutectic alloy, which had been rapidly cooled part way through the eutectic arrest and subsequently cooled more slowly to room temperature ; both undercooled and nodular graphite are evident. It appears that the microscopic form of the graphite resulting from the decomposition of the acicular carbide structure at low temperatures is different from that produced at high temperatures.

Examination of the Carbide

To examine the suggestion[1] that acicular carbide differs from the normal cementite found in white irons (based partly on the fact that this carbide is found in the white area of commercial castings which show inverse chill), a 2·88% C – 2·44% Si alloy was melted *in vacuo* and quenched from the liquid state. A Debye-Scherrer pattern of the powdered carbide, which had been extracted in an electrolytic cell, was obtained in a 19-cm. camera using filtered cobalt radiation. The pattern appeared to be the same as that produced by cementite extracted from an annealed hyper-eutectoid steel. The differences between the $\sin^2\theta$ values and those calculated from the parameters of the cementite structure could be extrapolated to zero when plotted against a suitable function.[3] Acicular carbide extracted from other specimens confirmed this result.

Effect of Silicon

To discover whether the formation of acicular carbide depends on the presence of silicon, a binary iron–carbon alloy (3·52% C) was melted and superheated in the high-vacuum apparatus. To ensure that degassing was as complete as possible, the ingot was allowed to solidify and was then remelted. When cooled in the vacuum furnace the alloy solidified with the normal structure, primary austenite dendrites (pearlite at room temperature) and globular cementite–austenite eutectic. When the alloy was quenched from the molten state in a stream of cold argon, an acicular eutectic structure was obtained. The close similarity between this structure and the acicular structure obtained in iron–carbon–silicon alloys can be seen by comparing Figs. 3 and 4.

DISCUSSION OF RESULTS

These experiments have shown that :

(1) High-purity hypo-eutectic iron–carbon–silicon alloys melted and cooled *in vacuo* solidify in the same manner as commercial cast irons containing undercooled graphite.

(2) When slowly cooled, the alloys first solidify in a metastable system, producing an austenite–carbide eutectic, which rapidly decomposes, in the solid state, to the undercooled graphite–austenite structure.

(3) This decomposition takes place at, or very near to, the metastable eutectic temperature.

(4) The metastable austenite–carbide eutectic (which, when retained at room temperature, has a characteristic acicular structure) is formed by undercooling the normal austenite–cementite eutectic.

(5) The carbide in the acicular structure is normal cementite (Fe_3C).

Cohen[4] has suggested that, in plain carbon steels, metastable cementite forms in preference to stable graphite, because the cementite precipitation is more easily nucleated. This explanation may be extended to the iron–carbon–silicon alloys under discussion. There are two sets of reactions to be considered—the precipitation of austenite–graphite or austenite–cementite from the melt, and the graphitization of the cementite–austenite eutectic complex. When silicon is present in the melt the rate of formation of graphite nuclei at or near the stable eutectic temperature is still very slow, thus permitting the formation of an austenite–cementite complex even when the alloy is slowly cooled. Since this eutectic also readily undercools when silicon is present, it may be assumed that the formation of cementite nuclei is also retarded. In the solid state, graphitization of the normal massive austenite–cementite eutectic proceeds by the formation and growth of nuclei in the austenite or at austenite–cementite boundaries. Schwartz[5] has shown that the rate of formation of graphite nuclei increases rapidly with an increase in temperature and silicon content. The present authors have obtained similar results in experiments using high-purity alloys. For example, with a 2·75% C, 1·18% S alloy the incubation period before microscopically visible graphite particles appear after isothermal treatment at 1140° C. is less than 16 sec. The location of graphite nuclei in the acicular cementite–austenite complex cannot be determined with certainty by direct microscopic observation, because the structure is very fine and decomposition is extremely rapid. There is no evidence that the cementite needles in the undercooled structure decompose *in situ*. It seems probable, therefore, that the mechanism of graphitization is the same as in the massive complex. If this is so, the more rapid decomposition of the acicular compared with the massive complex can be accounted for by (i) the greater degree of undercooling, (ii) the higher silicon contents of the alloys, and (iii) the larger austenite–cementite interfacial area per unit volume.

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Fig. 1—Acicular carbide and undercooled graphite. Etched in picral × 300

Fig. 2—Specimen containing both undercooled and spherulitic graphite. Etched in picral × 300

Fig. 3—Acicular carbide. Etched in picral × 250

Fig. 4—Quenched iron-carbon alloy. Etched in picral × 120

Cold Rolling with Strip Tension

Part II—COMPARISON OF CALCULATED AND EXPERIMENTAL RESULTS

By H. Ford, D.Sc.(Eng.), Ph.D., M.I.Mech.E., and F. Ellis, B.Sc.(Eng.)

SYNOPSIS

The approximate method of calculating roll force and roll torque, developed in Part I, is compared with the experimental results of Hessenberg and Sims recently published. The agreement is shown to be very satisfactory for a wide range of reductions and tensions.

It is shown that, when calculating the roll force and torque, the elastic recovery of the strip at exit cannot be neglected for normal passes.

For small passes the elastic deformation of the strip entering the pass may also be significant, and the combined contribution may amount to as much as 15% of the total roll force.

Introduction

In Part I,[1] various theories of cold rolling for the case where tension is applied to the strip were compared with each other and in particular with a new approximate method derived therein. The set of rolling conditions reported by Hill[2] was used for the comparisons, but a thorough comparison with experimental results of cold rolling with strip tension was not possible at that time because suitable data did not exist. The accurate experiments on tension rolling recently reported by Hessenberg and Sims[3] allow, however, such comparisons to be made.

Theories of rolling are necessarily based on certain assumptions, since factors that cannot always be accurately assessed or allowed for in the theory are involved in the actual process. Whilst the object of a theory is to give a closer insight into the mechanism of deformation in rolling, the theory should also be capable of simplification to allow practical calculations to be made with reasonable reliability. The method derived should require only a knowledge of measurable mechanical properties of the material being rolled, without recourse to other quantities such as those often involved in empirical formulae. These mechanical properties are the yield-stress curve (in this case, the yield stress plotted against the corresponding percentage reduction), and the coefficient of friction between the roll and strip.

In this Part of the paper the approximate method of calculation developed in Part I is examined in relation to the experimental results of Hessenberg and Sims. This method is based upon the theory previously put forward,[4] which itself was derived from Orowan's solution[5] of the differential equation of von Kármán.[6] The two main approximations (*see* Part I) are that the actual yield stress, which varies progressively through the roll gap as deformation advances, is replaced by the true mean yield stress for the pass, and that the term $\left(\frac{s}{\bar{k}} - 1\right)\frac{d(hk)}{d\phi}$ can be neglected in comparison with the term $hk\frac{d(s/k)}{d\phi}$.*

These approximations allow the roll force and torque to be calculated quickly from graphs, and in the following pages the results so calculated are compared with the experimental results.

EXPERIMENTAL DATA

The results given in Table II of the paper by Hessenberg and Sims[3] were used, but the actual thickness of the strip before and after each pass was used in equations (6) and (7) of Part I, since Hessenberg and Sims only give average values of the initial strip thickness. Examination of Tables I–III of the present paper, in which the information is reproduced, will show that the experiments covered reductions from about 30% to 50% on annealed and prestrained material, and tensions from zero to 22 tons/sq. in. Some special passes, in which no tension was applied, varied from 4% to 74% in a single pass. The roll finish and lubricant were unchanged throughout the tests, and the rolling speed was 40 ft./min.

The tests were performed on a 10 in. × 10 in. 2-high cold strip mill, which has been described elsewhere.[7, 8]

THE YIELD-STRESS CURVE

The yield-stress curves for each coil of strip used are given in Table I of Hessenberg and Sims' paper,[3] and are used in calculating the mean yield stress from the expression* :

$$\bar{k} = \text{mean yield stress} = \int_0^{\phi_1} \frac{k\,d\phi}{\phi_1}$$

The values of $\bar{k}$ are given in columns 5 of Tables I–III.

COEFFICIENT OF FRICTION

This quantity is difficult to measure directly, but there are two possibilities :

(1) The method of Bland (*loc. cit.*,[4] p. 161) gave a coefficient of about 0·055, for a few passes on

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* For notation, *see* Part I,[1] pp. 57, 58.

* Equation (5) of Part I.

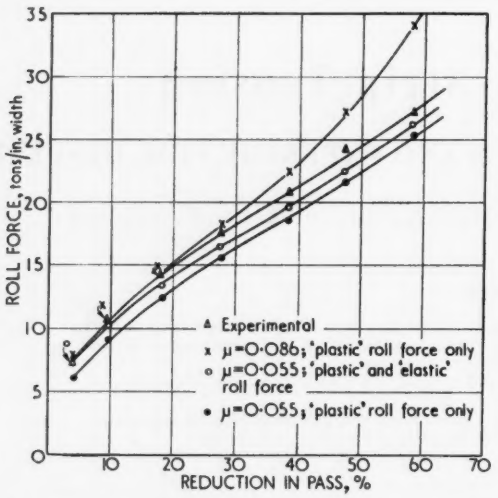
ROLL FORCE, tons/in. width
REDUCTION IN PASS, %
Experimental
x μ=0·086; 'plastic' roll force only
o μ=0·055; 'plastic' and 'elastic' roll force
• μ=0·055; 'plastic' roll force only

Fig. 1—Values of roll force for passes on prestrained strip. (No tension; $h_1 \simeq 0{\cdot}039$ in.; mild steel strip, initially about 0·063 in. thick)

mild-steel strip, under the same test conditions as in the Hessenberg and Sims' experiments. From these few tests it appears that the coefficient of friction is lower than is generally supposed.

In previous work,[9] values from 0·07 to 0·10 have been used as giving the best agreement between experimental and calculated values of roll force for a certain range of pass data. In such calculations only the plastic arc of contact was considered, and although a value of 0·08 is satisfactory for medium pass reductions, it may be very inaccurate at large and small pass reductions. Figure 1 shows an example from the present results, where $\mu = 0{\cdot}086$ gives good agreement for the smaller passes but is badly out at higher passes; a coefficient of 0·055 gives a curve which is too low, but its shape agrees well with the experimental curve. In both cases only the plastic arc was considered.

(2) Another test confirms the lower coefficient of friction. It is possible to roll a strip which is so thick that the angle of entry is much larger than the angle of friction. The strip can be made to enter by thinning its front end in steps which, as they pass into the roll gap, cause the pass reduction to increase until the neutral point reaches exit, when skidding of the rolls on the strip occurs. At this moment the roll force and torque are noted, together with the reduction in the pass. The same experiment can be performed without varying the strip thickness, if it is possible to screw down on the strip during rolling.

The effect of this is to increase the outward horizontal component of the normal roll pressure so that, near the entry, it is greater than the inward horizontal component of the frictional force, and is thus equivalent to a back tension.

Using Orowan's theory it is possible to calculate the coefficient of friction required both to give slipping at this particular arc of contact and to correspond to the roll force and torque obtained at the moment of slipping. From a few tests on mild steel, using a commercial rolling oil, the method gave $\mu = 0{\cdot}045$ to $0{\cdot}057$.

In view of this evidence—meagre, but nevertheless the only experimental evidence available—it was decided to take $\mu = 0{\cdot}055$ as the most reasonable value.

ELASTIC DEFORMATION OF THE STRIP

Little attention has been paid in the past to the effect of the elastic deformation of the strip. It is clear that, particularly at exit, there must be an area of contact where the roll and strip are only elastically deformed. The effect of this is threefold: the total roll force is thereby directly augmented; the friction between the roll and strip over the elastic arc increases the 'friction hill,' so raising the plastic roll force; and the effective roll radius is modified.

Except for very small passes, the elastic compression at entry causes negligible difference in the roll force. The contribution of the elastic effect at exit, however, cannot be neglected; in small passes it may amount to 15% of the total roll force, and in normal reductions is seldom less than 4%.

Making certain approximations and assumptions it can be shown* that, for mild steel, the elastic contribution to the roll force is given by:

at entry,

$$P_{e_1} = 1{\cdot}61 \times 10^{-5} \sqrt{\frac{R'}{\delta}}(k - \sigma_1)^2 h_1 \quad \ldots\ldots(13)\dagger$$

at exit,

$$P_{e_2} = 5{\cdot}29 \times 10^{-3} \sqrt{R' h_2}(k - \sigma_2)^{\frac{3}{2}} \quad \ldots\ldots(6)$$

where:

σ_1 = back tension, *i.e.*, the effective tension at the start of the plastic deformation region
$= \sigma_1' - \sigma_{e_1}$, where σ_1' = externally applied back tension and σ_{e_1} = tension created by the friction over the elastic arc of contact on the entry side

σ_2 = front tension, *i.e.*, the effective tension at the end of the plastic zone
$= \sigma_2' - \sigma_{e_2}$, where σ_2' = externally applied front tension and σ_{e_2} = tension created by the friction over the elastic arc of contact on the exit side
$= 2\mu P_{e_2}/h_2$.

The latter is a compressive stress reducing the effect of any externally applied tension. In 'no tension' rolling (as in sheet rolling) it produces compressive stresses—corresponding to 'negative tensions'—which will increase the plastic roll force.

The tension terms in the torque equation

$$G = R\bar{k}\delta'\left(1 - \frac{\sigma_1}{\bar{k}}\right)f_5 + \frac{R}{2}(\sigma_1' h_1 - \sigma_2' h_2)$$

do not involve the 'elastic' tension components σ_{e_1} and σ_{e_2}, because these tensions, which occur at the start and end of the plastic zone, are balanced by the frictional force over the elastic arcs of contact. They affect the term $(1 - \sigma_1/\bar{k})$—here σ_1 is

* *See* Part III, p. 248. Young's modulus has been taken as 3400 tons/sq. in., and Poisson's ratio as 0·3.

† The equation numbers throughout Part II correspond to those in Part III.

($\sigma_1' - \sigma_{e_1}$)—but usually σ_{e_1} is negligible. The function f_5 is affected because it depends upon B ($= \log_e b$, where $b = \{1 - \sigma_2/\bar{k}\}/\{1 - \sigma_1/\bar{k}\}$), and σ_2 ($= \sigma_2' - \sigma_{e_2}$) is also more or less affected. The term δ' is the reduction in the pass, allowing for the slight elastic recovery of the strip; *i.e.*, $\delta' = \delta + \delta_2 + \delta_t$. These facts are illustrated in Fig. 2.

The radius of the flattened arc of contact is affected by these elastic contributions to the roll force. The whole pressure distribution is brought nearer to the elliptical distribution assumed by Hitchcock.[10] From Prescott's basic equations[11] it can be shown that*

$$R' = R\left\{1 + \frac{2cP}{\{\sqrt{\delta + \delta_2 + \delta_t} + \sqrt{\delta_1}\}^2}\right\} \quad \ldots\ldots(19)$$

where :

c = constant for the material of the rolls
= $1{\cdot}67 \times 10^{-4}$ for steel rolls (inch and ton units)
P = total roll force (elastic + plastic).

METHOD OF CALCULATION

The method described in Part I[1] assumes that the yield-stress curve can be simplified to a mean value throughout the arc of contact. This assumption requires that in some places the actual yield stresses at entry and exit—for example, in the factors $(1 - \sigma_1/k_1)$ and $(1 - \sigma_2/k_2)$—shall be replaced by the mean value $\bar{k}$, for consistency in the calculations for the plastic zone. However, in calculating the elastic strains and the elastic roll force, the actual yield stress at the entry or exit point is taken, because the formulae depend on the condition of yield at the start or finish of the plastic zone. Calculation shows that there is very little difference whether the mean value or the actual values are taken.

COMPARISON OF EXPERIMENTAL AND CALCULATED VALUES

In Tables I–III the main steps in the calculations are recorded, together with the error in the calculated roll force and torque, expressed as :

$$\text{Percentage error} = \frac{\text{Experimental value} - \text{calculated value}}{\text{Experimental value}} \times 100$$

Hessenberg and Sims, on p. 156 of their paper,[3] give the most probable values of roll force and torque for all 40% nominal passes, and the corresponding values will now be calculated by the present method, as an example.

* *See* Part III, p. 249.

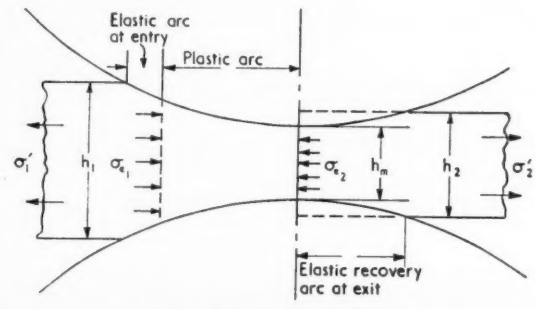

Fig. 2—Element in roll gap

Table I—EXPERIMENTAL AND CALCULATED VALUES OF ROLL FORCE AND TORQUE
0·08% C steel; nominal initial thickness 0·063 in.; no tensions; $\mu = 0{\cdot}055$

Coil No. Ref. Letter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Thickness of Strip, in.		Reduction	Reduction, %	Mean Yield Stress, tons/sq. in.	Deformed Roll Radius, in.				Roll Force, tons per inch width								Roll Torque, tons-in. per inch width			
	At Entry h_1	At Exit h_2	δ'	r	$\bar{k}$	R'	B	a	f_5	Calculated				Experimental	Error		f_5	Calculated	Experimental	Error	
										P_{e_1}	P_{e_2}	P_p	P_{total}	P_E	Actual	%		G	G_E	Actual	%
1st Passes Average of all values	0·063	0·0378	0·0253	40·0	37·6	5·90	0·060	0·688	1·085	...	0·794	15·71	16·5	16·56	−0·06	− 0·4	0·519	2·44	2·37	+0·07	+ 2·9
1st Passes K	0·0637	0·0536	0·0102	15·9	28·2	6·13	0·044	0·589	1·090	...	0·63	7·75	8·4	8·6	−0·2	2·3	0·535	0·76	0·75	+0·01	+ 1·3
H	0·0630	0·0512	0·0119	19·0	29·8	6·17	0·046	0·602	1·091	...	0·65	8·82	9·5	10·2	−0·7	6·9	0·534	0·95	0·97	−0·02	+ 2·1
B	0·0640	0·0475	0·0166	25·7	32·8	6·23	0·050	0·630	1·097	...	0·72	11·58	12·3	12·5	−0·2	1·6	0·534	1·45	1·32	+0·13	+ 9·8
X	0·0640	0·0439	0·0202	31·3	34·6	5·99	0·052	0·642	1·090	...	0·73	13·11	13·8	14·0	−0·2	1·4	0·528	1·84	1·71	+0·13	+ 7·6
C	0·0635	0·0384	0·0252	39·5	36·4	5·93	0·056	0·685	1·085	...	0·74	15·28	16·0	16·0	0	0	0·520	2·37	2·22	+0·15	+ 7·1
V	0·0637	0·0318	0·0320	49·8	38·6	5·83	0·064	0·745	1·063	...	0·74	17·70	18·4	17·9	+0·5	2·8	0·506	3·11	2·82	+0·29	+10·3
P	0·0635	0·0244	0·0392	61·7	40·4	5·73	0·076	0·845	1·042	...	0·70	20·00	20·7	19·2	+1·5	7·8	0·491	3·87	3·42	+0·45	+13·2
G	0·0634	0·0166	0·0469	73·9	42·8	5·68	1·098	1·017	1·023	...	0·665	22·55	23·2	20·5	+2·7	13·1	0·473	4·72	4·67	+0·05	+ 1·1
2nd Passes A	0·0393	0·0378	0·0016	4·0	43·7	9·90	0·075	0·890	1·092	0·101	1·132	6·03	7·26	7·4	−0·14	1·9	0·546	0·192	0·23	−0·04	−16·5
B	0·0394	0·0356	0·0039	9·7	44·3	8·41	0·0649	0·846	1·128	0·05	1·03	9·02	10·1	10·8	−0·7	6·4	0·560	0·485	0·53	−0·04	− 8·5
C	0·0391	0·0321	0·0071	18·2	45·4	7·69	0·0658	0·850	1·165	...	0·89	12·38	13·3	14·3	−1·0	7·0	0·568	0·91	0·99	−0·08	− 8·1
D	0·0393	0·0283	0·01109	28·2	45·9	7·24	0·0714	0·880	1·190	...	0·86	15·50	16·4	17·7	−1·3	7·3	0·573	1·45	1·58	−0·13	− 8·2
E	0·0392	0·0241	0·0152	38·6	46·9	6·98	0·0779	0·935	1·213	...	0·83	18·50	19·3	20·7	−1·4	6·8	0·572	2·03	2·17	−0·14	− 6·5
F	0·0395	0·0206	0·0190	47·9	48·3	6·90	0·0889	1·005	1·225	...	0·82	21·43	22·3	24·2	−1·9	7·9	0·559	2·54	2·80	−0·26	−11·9
G	0·0388	0·0159	0·02296	58·8	49·7	6·87	0·1026	1·140	1·273	...	0·78	25·20	26·0	27·2	−1·2	4·3	0·579	3·29	3·27	+0·02	+ 0·6

Table II—EXPERIMENTAL AND CALCULATED VALUES OF ROLL FORCE AND ROLL TORQUE FOR ANNEALED STRIP

0·08% C steel; nominal initial thickness 0·063 in.; tensions applied; $\mu = 0{\cdot}055$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Thickness of Strip, in.		Reduction	Reduction, %	Mean Yield Stress, tons/sq. in.	Deformed Roll Radius, in.	Tensions					Roll Force, tons per inch width							Roll Torque, tons-in. per inch width			
											Calculated			Experimental	Error*			Calculated	Experimental	Error*	
At Entry h_1	At Exit h_2	δ'	r	$\bar{k}$	R'	σ_1	σ_2	B	a	f_2	Pe_2	P_p	P_{total}	P_E	Actual	%	f_1	G	G_E	Actual	%
Coil 2. First Passes. Nominal Reduction 30%																					
0·0643	0·0455	0·0188	29·3	34·0	6·00	0	0·15	0	0·633	1·061	0·68	12·2	12·9	13·5	−0·6	− 4	0·526	1·47	1·39	+0·08	+ 6
0·0651	0·0460	0·0191	29·4	34·0	5·92	0	9·1	−0·31	0·626	0·980	0·46	11·2	11·7	12·6	−0·9	− 7	0·494	0·35	0·47	−0·12	...
0·0643	0·0450	0·0193	30·0	34·4	5·88	0	10·1	−0·35	0·630	0·962	0·45	11·2	11·7	12·2	−0·5	− 4	0·503	0·41	0·40	+0·01	+ 2
0·0648	0·0451	0·0197	30·4	34·4	5·81	0	15·3	−0·62	0·626	0·860	0·33	10·1	10·4	11·6	−1·2	−10	0·467	−0·23	−0·13	−0·10	...
0·0640	0·0449	0·0191	29·9	34·3	5·77	0	19·2	−0·83	0·624	0·758	0·28	8·8	9·0	10·6	−1·6	−14	0·416	−0·88	−0·65	−0·23	...
0·0648	0·0445	0·0203	31·4	34·6	5·97	0	−1·83	+0·05	0·638	1·085	0·74	13·1	13·8	14·0	−0·2	− 1	0·527	1·83	1·74	+0·09	+ 5
0·0642	0·0447	0·0195	30·3	34·4	6·00	0	−1·83	+0·05	0·639	1·070	0·75	12·6	13·4	13·9	−0·5	− 4	0·528	1·76	1·69	+0·07	+ 4
0·0643	0·0443	0·0200	31·1	34·5	5·96	0	−1·84	+0·05	0·639	1·070	0·74	12·9	13·6	13·8	−0·2	− 1	0·527	1·80	1·75	+0·05	+ 3
0·0643	0·0449	0·0195	30·2	34·4	5·95	2·7	−1·80	+0·14	0·634	1·073	0·74	11·6	12·3	13·2	−0·9	− 7	0·529	2·05	1·99	+0·06	+ 3
0·0645	0·0458	0·0188	29·0	34·0	5·99	2·8	−1·80	+0·14	0·630	1·076	0·73	11·3	12·0	12·9	−0·9	− 7	0·535	2·00	1·96	+0·04	+ 2
0·0644	0·0451	0·0194	30·0	34·4	5·95	2·8	−1·80	+0·14	0·632	1·076	0·75	11·5	12·3	13·1	−0·8	− 6	0·528	2·03	1·99	+0·04	+ 2
0·0644	0·0454	0·0191	29·5	34·0	5·88	2·8	6·40	−0·09	0·627	1·035	0·50	10·9	11·4	12·0	−0·6	− 5	0·521	1·14	1·15	−0·01	− 1
0·0645	0·0456	0·0190	29·3	34·0	5·84	3·0	9·8	−0·25	0·623	0·987	0·44	10·2	10·6	11·5	−0·9	− 7	0·511	0·76	0·70	+0·06	+ 8
0·0644	0·0457	0·0188	29·1	34·0	5·86	3·1	10·6	−0·27	0·623	0·961	0·42	10·0	10·4	11·5	−1·1	− 9	0·510	0·67	0·69	−0·02	− 3
0·0648	0·0454	0·0195	29·9	34·3	5·78	3·1	15·2	−0·50	0·621	0·899	0·32	9·6	9·9	10·8	−0·9	− 8	0·485	0·15	0·25	−0·10	...
0·0644	0·0451	0·0194	30·0	34·4	5·71	3·1	19·5	−0·75	0·620	0·796	0·23	8·4	8·6	9·9	−1·3	−13	...	...	...	...	...
0·0643	0·0445	0·0199	30·8	34·4	5·83	6·2	−1·8	+0·25	0·630	1·086	0·73	10·5	11·2	11·8	−0·6	− 5	0·522	2·42	2·40	+0·02	+ 1
0·0644	0·0444	0·0201	31·1	34·5	5·83	6·3	−1·8	+0·26	0·632	1·085	0·73	10·4	11·1	11·9	−0·8	− 7	0·533	2·50	2·46	+0·04	+ 2
0·0647	0·0444	0·0204	31·3	34·6	5·81	6·4	−1·8	+0·26	0·631	1·085	0·73	10·6	11·4	11·8	−0·4	− 3	0·531	2·53	2·41	+0·12	+ 5
0·0645	0·0455	0·0191	29·5	34·0	5·85	6·2	0·2	+0·19	0·625	1·083	0·68	10·3	11·0	11·6	−0·6	− 5	0·532	2·19	2·11	+0·08	+ 4
0·0645	0·0455	0·0191	29·4	34·0	5·83	6·3	4·6	+0·19	0·624	1·079	0·56	10·1	10·7	11·3	−0·6	− 5	0·531	1·73	1·67	+0·06	+ 4
0·0644	0·0459	0·0186	28·7	33·8	5·81	6·2	8·5	−0·09	0·620	1·035	0·47	9·5	10·0	10·7	−0·7	− 6	0·521	1·24	1·18	+0·06	+ 5
0·0646	0·0461	0·0186	28·7	33·8	5·71	6·5	9·5	−0·12	0·614	1·028	0·44	9·3	9·7	10·6	−0·9	− 8	0·519	1·15	1·12	+0·03	+ 3
0·0642	0·0453	0·0190	29·5	34·0	5·76	6·3	10·5	−0·16	0·620	1·015	0·43	9·4	9·8	10·4	−0·6	− 6	0·517	1·07	1·08	−0·01	− 1
0·0643	0·0464	0·0180	27·8	33·6	5·78	6·4	11·4	−0·20	0·615	1·004	0·42	8·9	9·3	10·1	−0·8	− 8	0·516	0·89	0·86	+0·03	+ 4
0·0648	0·0458	0·0191	29·3	34·0	5·71	6·2	14·6	−0·36	0·615	0·951	0·33	8·9	9·2	9·7	−0·5	− 5	0·500	0·57	0·62	−0·05	− 8
0·0644	0·0459	0·0186	28·7	33·8	5·68	6·2	18·4	−0·60	0·613	0·860	0·25	7·8	8·1	9·1	−1·0	−11	0·467	0·03	1·14	...	...
0·0641	0·0447	0·0195	30·2	34·4	6·02	0	−1·8	+0·05	0·640	1·073	0·75	12·7	13·5	14·2	−0·7	− 5	0·529	1·75	1·66	+0·09	+ 5
0·0645	0·0446	0·0200	30·9	34·4	5·99	0	−1·8	+0·05	0·638	1·073	0·74	12·9	13·6	14·0	−0·4	− 3	0·528	1·80	1·68	+0·12	+ 7
Coil 3. First Passes. Nominal Reduction 50%																					
0·0631	0·0327	0·0305	48·2	40·2	5·88	0	1·5	−0·04	0·74	1·050	0·69	17·8	18·5	17·6	+0·9	− 5	0·506	2·77	2·45	+0·32	+13
0·0631	0·0327	0·0305	48·2	40·2	5·85	0	5·7	−0·16	0·74	0·997	0·60	17·3	17·9	17·1	+0·8	+ 5	0·505	2·44	2·15	+0·29	+13
0·0630	0·0336	0·0295	46·6	40·0	5·82	0	7·4	−0·20	0·72	1·016	0·56	16·8	17·3	16·9	+0·4	+ 3	0·502	2·18	1·96	+0·22	+11
0·0629	0·0332	0·0297	47·2	40·2	5·81	0	9·5	−0·26	0·73	0·997	0·51	16·5	17·0	16·5	+0·5	+ 3	0·499	2·03	1·75	+0·28	+16
0·0631	0·0336	0·0295	46·8	40·0	5·77	0	13·4	−0·40	0·72	0·959	0·43	15·8	16·2	15·9	+0·3	+ 2	0·492	1·64	1·43	+0·21	+15
0·0628	0·0338	0·0290	46·2	39·9	5·73	0	17·1	−0·55	0·72	0·920	0·36	14·9	15·3	15·3	0	0	0·483	1·25	1·15	+0·10	+ 9
0·0636	0·0317	0·0319	50·1	40·8	5·75	2·9	−2·7	+0·13	0·75	1·060	0·79	17·1	17·9	16·4	+1·5	+ 9	0·506	3·50	3·08	+0·42	+14
0·0631	0·0326	0·0306	48·3	40·2	5·85	3·1	−2·7	+0·14	0·74	1·067	0·79	16·7	17·5	17·0	+0·5	+ 3	0·515	3·87	3·04	+0·33	+11
0·0633	0·0325	0·0309	48·7	40·2	5·79	3·1	5·9	−0·08	0·73	1·035	0·59	16·1	16·7	15·8	+0·9	+ 6	0·503	2·70	2·40	+0·30	+12
0·0631	0·0339	0·0293	46·2	39·9	5·76	3·1	7·1	−0·11	0·72	1·033	0·56	15·6	16·1	15·9	+0·2	+ 2	0·506	2·44	2·20	+0·24	+11
0·0631	0·0329	0·0303	47·9	40·2	5·76	3·1	9·7	−0·18	0·73	1·020	0·51	15·7	16·2	15·4	+0·8	+ 5	0·502	2·34	2·07	+0·27	+13
0·0632	0·0332	0·0301	47·5	40·2	5·72	2·9	13·8	−0·34	0·72	0·973	0·41	15·0	15·4	14·8	+0·6	+ 4	0·495	1·95	1·73	+0·22	+13
0·0632	0·0343	0·0290	45·7	39·7	5·67	3·1	16·6	−0·45	0·71	0·945	0·37	13·9	14·3	14·3	0	0	0·490	1·55	1·43	+0·12	+ 8
0·0649	0·0318	0·0332	51·0	41·2	5·80	6·0	−2·7	+0·22	0·74	1·069	0·80	16·5	17·3	15·6	+0·1	+11	0·503	3·89	3·39	+0·50	+15
0·0650	0·0324	0·0327	50·1	40·8	5·80	6·3	−2·7	+0·23	0·74	1·079	0·80	16·1	16·9	16·0	+0·9	+ 6	0·506	3·85	3·37	+0·48	+14
0·0649	0·0325	0·0325	49·9	40·8	5·77	6·2	1·9	+0·14	0·73	1·068	0·68	15·9	16·6	15·4	+1·2	+ 8	0·503	3·47	3·30	+0·47	+16
0·0651	0·0327	0·0325	49·7	40·7	5·74	6·2	5·8	+0·01	0·73	1·054	0·60	15·7	16·3	15·0	+1·3	+ 9	0·502	3·17	2·72	+0·45	+16
0·0647	0·0335	0·0313	48·2	40·2	5·73	6·3	8·1	−0·05	0·72	1·035	0·55	14·8	15·4	15·0	+0·4	+ 3	0·502	2·82	2·46	+0·36	+15
0·0645	0·0327	0·0318	49·3	40·5	5·72	6·6	10·2	−0·11	0·73	1·025	0·50	14·8	15·3	14·5	+0·8	+ 5	0·500	2·78	2·42	+0·36	+15
0·0648	0·0336	0·0313	48·2	40·2	5·69	6·2	14·2	−0·27	0·71	0·980	0·42	13·9	14·3	14·3	0	0	0·495	2·30	2·04	+0·26	+13
0·0653	0·0332	0·0322	49·1	40·5	5·67	6·2	18·3	−0·43	0·72	0·943	0·34	13·8	14·1	13·8	+0·3	+ 2	0·486	2·04	1·75	+0·29	+16
0·0650	0·0317	0·0334	51·3	41·2	5·75	9·1	−2·7	+0·31	0·74	1·070	0·79	15·0	15·8	14·6	+1·2	+ 8	0·503	4·13	3·65	+0·48	+13
0·0645	0·0315	0·0331	51·1	41·2	5·74	9·4	−2·7	+0·32	0·74	1·072	0·78	14·9	15·7	14·3	+1·4	+10	0·503	4·13	3·59	+0·54	+15
0·0651	0·0320	0·0332	50·8	41·0	5·73	9·3	2·3	+0·20	0·74	1·064	0·68	14·9	15·6	14·5	+1·1	+ 8	0·503	3·78	3·32	+0·46	+14
0·0649	0·0328	0·0321	49·5	40·7	5·69	9·3	5·8	+0·10	0·72	1·067	0·59	14·3	14·9	14·0	+0·9	+ 6	0·501	3·36	2·99	+0·37	+12
0·0644	0·0332	0·0312	48·4	40·3	5·67	9·4	8·1	+0·04	0·72	1·054	0·54	13·6	14·1	13·7	+0·4	+ 4	0·508	3·12	2·72	+0·40	+15
0·0651	0·0324	0·0327	50·2	40·8	5·67	9·1	10·9	−0·06	0·73	1·035	0·48	14·1	14·6	13·5	+1·1	+ 8	0·499	2·77	2·62	+0·15	+ 6
0·0647	0·0329	0·0318	49·1	40·5	5·64	9·4	14·1	−0·16	0·72	1·012	0·42	13·5	13·9	13·0	+0·9	+ 7	0·498	2·70	2·34	+0·36	+15
0·0646	0·0327	0·0319	49·4	40·6	5·62	9·3	18·8	−0·36	0·72	0·964	0·33	12·8	13·1	12·5	+0·6	+ 5	0·491	2·30	1·98	+0·32	+16

* When experimental torque is low, percentage errors are not significant and have been omitted

0·0651	0·0324	0·0327	50·2	40·5	5·67	7·1	10·7	−0·06	0·76	1·012	0·42	13·5	13·9	13·0	+0·9	+ 7	0·498	2·77	2·62	+0·15	+ 6	
0·0647	0·0329	0·0318	49·1	40·5	5·64	9·4	14·1	−0·16	0·72	1·012	0·42	13·5	13·9	13·0	+0·9	+ 7	0·498	2·70	2·34	+0·36	+15	
0·0646	0·0327	0·0319	49·4	40·6	5·62	9·3	18·8	−0·36	0·72	0·964	0·33	12·8	13·1	12·5	+0·6	+ 5	0·491	2·30	1·98	+0·32	+16	

* When experimental torque is low, percentage errors are not significant and have been omitted

Table III

EXPERIMENTAL AND CALCULATED VALUES OF ROLL FORCE AND ROLL TORQUE FOR PRESTRAINED STRIP

0·08% C steel ; nominal thickness 0·063 in. ; tensions applied ; $\mu = 0·055$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Thickness of Strip, in.		Reduction	Reduction, %	Mean Yield Stress, tons/sq. in.	Deformed Roll Radius, in.	Tensions					Roll Force, tons per inch width							Roll Torque, tons-in. per inch width			
											Calculated			Experimental	Error			Calculated	Experimental	Error	
At Entry h_1	At Exit h_2	δ'	r	$\bar{k}$	R'	σ_1	σ_2	B	a	f_3	P_{e_2}	P_p	P_{total}	P_E	Actual	%	f_5	G	G_E	Actual	%
Coil 5. Second Passes. Nominal Reduction 30%																					
0·0382	0·0265	0·0118	30·5	46·8	7·02	0	2·6	−0·06	0·896	1·161	0·73	15·6	16·3	16·8	−0·5	−3	0·567	1·20	1·25	−0·05	−4
0·0376	0·0260	0·0116	30·9	47·2	6·90	0	8·0	−0·18	0·895	1·114	0·57	15·0	15·5	15·8	−0·3	−1	0·557	0·87	0·87	0	0
0·0381	0·0259	0·0123	32·2	46·9	6·84	0	9·6	−0·23	0·895	1·089	0·53	14·7	15·2	15·8	−0·6	−4	0·557	0·80	0·90	−0·10	−11
0·0379	0·0254	0·0126	33·0	47·0	6·69	0	14·7	−0·37	0·893	1·040	0·43	14·2	16·6	15·0	−0·4	−2	0·538	0·54	0·63	−0·09	−14
0·0382	0·0252	0·0131	34·0	47·1	6·50	0	19·3	−0·53	0·884	0·984	0·34	13·5	13·8	14·1	−0·3	−2	0·519	0·29	0·40	−0·11	...
0·0383	0·0264	0·0120	31·3	46·9	6·95	5·8	−3·5	+0·20	0·894	1·239	0·83	14·6	15·4	16·5	−1·1	−6	0·578	1·97	1·99	−0·02	−1
0·0384	0·0263	0·0122	31·5	47·3	6·91	5·8	−3·5	+0·20	0·893	1·236	0·83	14·9	15·7	16·4	−0·7	−4	0·580	1·83	2·00	−0·07	−8
0·0389	0·0262	0·0128	32·5	46·8	6·80	5·7	0·7	+0·11	0·886	1·208	0·75	14·5	15·3	16·0	−0·7	−4	0·571	1·79	1·77	+0·02	+1
0·0386	0·0264	0·0123	31·8	46·5	6·76	5·7	4·8	+0·02	0·880	1·153	0·63	13·5	14·1	15·3	−1·2	−8	0·545	1·42	1·48	−0·06	−4
0·0384	0·0259	0·0126	32·6	46·9	6·66	5·6	7·8	−0·06	0·882	1·153	0·56	13·7	14·2	14·8	−0·6	−4	0·562	1·24	1·30	−0·06	−5
0·0383	0·0262	0·0122	31·5	46·8	6·68	5·8	9·6	−0·10	0·878	1·143	0·52	13·4	13·9	14·5	−0·6	−4	0·561	1·21	1·20	+0·01	+1
0·0388	0·0261	0·0128	32·8	46·8	6·55	5·8	13·9	−0·22	0·871	1·099	0·44	13·0	14·4	14·0	−0·6	−4	0·549	0·97	1·00	+0·03	−3
0·0383	0·0255	0·0129	33·2	46·9	6·42	5·9	18·9	−0·38	0·874	1·032	0·34	12·2	12·5	13·0	−0·5	−3	0·535	0·68	0·73	−0·05	−7
0·0381	0·0248	0·0134	34·8	47·3	6·50	11·7	−3·6	+0·36	0·890	1·250	0·80	13·1	13·9	14·0	0·1	−1	0·574	2·47	2·42	+0·05	+2
0·0378	0·0244	0·0135	34·4	47·3	6·47	11·9	−3·6	+0·36	0·896	1·255	0·79	13·1	13·9	13·9	0	0	0·576	2·49	2·41	+0·08	+3
0·0384	0·0251	0·0134	35·5	46·9	6·44	11·3	1·1	+0·25	0·881	1·231	0·70	12·8	13·5	13·5	0	0	0·572	2·17	2·12	+0·05	+2
0·0383	0·0253	0·0131	33·9	46·9	6·40	11·7	5·6	+0·16	0·877	1·209	0·59	12·2	12·8	12·9	−0·1	−1	0·568	1·90	1·90	0	0
0·0380	0·0256	0·0125	32·8	46·9	6·42	11·9	8·2	−0·12	0·871	1·130	0·55	11·3	11·8	12·6	−0·8	−6	0·556	1·67	1·69	−0·02	−1
0·0382	0·0256	0·0127	32·7	46·9	6·38	11·6	10·2	+0·04	0·867	1·179	0·50	11·7	12·2	12·3	−0·1	−1	0·565	1·59	1·52	+0·07	+5
0·0379	0·0259	0·0121	31·8	47·0	6·39	11·8	14·9	−0·09	0·865	1·149	0·41	11·3	11·7	11·8	−0·1	−1	0·558	1·23	1·26	−0·03	−2
0·0383	0·0261	0·0123	31·8	46·9	6·25	11·7	18·6	0·22	0·850	1·082	0·34	10·5	10·8	10·9	0	0	0·545	0·98	1·01	−0·03	−3
Coil 6. Second Passes. Nominal Reduction 50%																					
0·0385	0·0184	0·0202	52·1	49·4	6·67	0	0	0	1·047	1·213	0·70	21·9	22·6	22·8	−0·2	−1	0·568	2·62	2·53	+0·09	+3
0·0388	0·0183	0·0206	52·8	49·3	6·56	0	5·0	−0·11	1·041	1·178	0·59	21·2	21·8	21·8	0	0	0·561	2·43	2·36	+0·07	+3
0·0385	0·0187	0·0199	51·5	49·3	6·59	0	6·8	−0·15	1·031	1·164	0·57	20·7	21·2	21·4	−0·2	−1	0·561	2·26	2·23	+0·03	+1
0·0383	0·0178	0·0206	53·5	49·4	6·51	0	9·8	−0·22	1·052	1·150	0·50	20·7	21·2	20·9	+0·3	+1	0·551	2·21	2·19	+0·02	+1
0·0384	0·0181	0·0204	52·9	49·4	6·47	0	14·8	−0·36	1·041	1·105	0·42	19·7	20·1	20·3	−0·2	−1	0·553	1·99	1·99	0	0
0·0384	0·0181	0·0204	52·9	49·4	6·41	0	17·8	−0·45	1·037	1·073	0·36	19·1	19·4	19·5	+0·1	0	0·545	1·83	1·83	0	0
0·0385	0·0189	0·0197	51·0	49·2	6·57	5·9	−4·6	+0·22	1·026	1·257	0·79	19·4	20·2	21·0	−0·8	0	0·561	2·94	2·93	+0·01	0
0·0382	0·0173	0·0210	54·6	49·4	6·46	6·7	−4·9	+0·24	1·063	1·263	0·78	19·7	20·5	20·7	−0·1	0	0·570	3·18	2·98	+0·02	+6
0·0385	0·0185	0·0201	52·0	49·3	6·49	6·5	0·1	+0·13	1·030	1·223	0·69	18·8	19·5	20·4	−0·9	−4	0·566	2·84	2·82	+0·02	+1
0·0385	0·0182	0·0204	52·7	49·3	6·41	6·4	5·1	+0·03	1·033	1·208	0·58	18·6	19·2	19·4	−0·2	−1	0·564	2·67	2·58	+0·09	+3
0·0385	0·0176	0·0210	54·3	49·4	6·32	6·5	7·6	−0·03	1·042	1·190	0·53	18·5	19·0	18·7	+0·3	+2	0·559	2·61	2·47	+0·14	+5
0·0383	0·0180	0·0204	53·1	49·4	6·36	6·6	9·4	−0·07	1·033	1·184	0·50	18·1	18·6	18·7	0	0	0·559	2·49	2·43	+0·16	+2
0·0385	0·0179	0·0207	53·5	49·3	6·28	6·4	14·7	−0·22	1·030	1·126	0·41	17·4	17·8	18·0	−0·1	−1	0·553	2·29	2·20	+0·09	+4
0·0382	0·0173	0·0210	54·9	49·4	6·18	6·5	20·5	−0·40	1·040	1·085	0·32	16·6	17·0	16·8	+0·2	+1	0·548	2·10	2·00	+0·10	+5
0·0386	0·0176	0·0211	54·7	49·4	6·28	12·3	−4·8	+0·38	1·049	1·290	0·77	17·3	18·1	18·2	−0·1	0	0·569	3·39	3·07	+0·32	+ 9
0·0386	0·0168	0·0219	56·4	49·4	6·22	12·3	−4·9	+0·38	1·059	1·286	0·76	17·5	18·2	17·9	+0·3	+2	0·566	3·46	3·11	+0·35	+10
0·0382	0·0171	0·0211	55·1	49·4	6·21	12·4	−0·4	+0·37	1·048	1·281	0·67	17·1	17·7	17·3	+0·4	+2	0·566	3·22	2·91	+0·31	+10
0·0387	0·0176	0·0211	54·6	49·4	6·15	12·4	5·4	+0·17	1·027	1·228	0·56	16·4	17·0	16·6	+0·4	+2	0·559	2·71	2·71	0	0
0·0383	0·0175	0·0209	54·3	49·4	6·15	12·4	7·8	+0·11	1·031	1·219	0·52	16·0	16·6	16·3	+0·3	+2	0·559	2·84	2·52	+0·32	+11
0·0384	0·0176	0·0209	54·3	49·4	6·15	12·3	10·9	+0·05	1·027	1·204	0·48	15·9	16·4	16·3	+0·1	+1	0·559	2·74	2·52	+0·22	+ 8
0·0385	0·0179	0·0206	53·3	49·3	6·09	12·3	15·1	−0·08	1·014	1·168	0·39	15·3	15·6	15·4	+0·3	+2	0·555	2·51	2·31	+0·20	+ 8
0·0387	0·0182	0·0205	53·0	49·3	6·06	11·9	19·1	−0·21	1·002	1·121	0·23	14·7	15·1	14·8	+0·3	+2	0·546	2·27	2·07	+0·20	+ 9
0·0383	0·0190	0·0194	50·6	49·3	6·78	0	−4·7	+0·09	1·040	1·237	0·81	22·0	22·8	23·4	−0·6	−3	0·571	2·71	2·68	+0·03	+ 1
0·0383	0·0185	0·0198	51·7	49·4	6·72	0	−4·8	+1·07	1·049	1·234	0·81	22·2	23·0	23·2	−0·2	−1	0·558	2·79	2·67	+0·12	+ 4
0·0388	0·0182	0·0206	53·0	49·4	6·69	0	−4·8	+1·07	1·055	1·229	0·79	22·4	23·2	23·7	−0·5	−2	0·555	2·89	2·71	+0·18	+ 6
0·0381	0·0176	0·0206	53·8	49·4	6·68	0	−5·0	+1·10	1·070	1·243	0·80	22·7	23·5	23·3	+0·2	+1	0·553	2·89	2·71	+0·18	+ 6

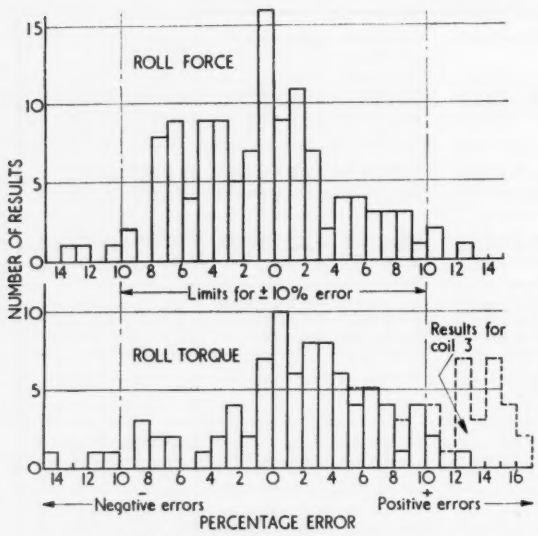

Fig. 3—Distribution of errors

It is assumed that the yield-stress curves are those for coils 4, 5, and 6 (since the other coils apply to tension passes), and therefore the average of the yield-stress curves for these three coils was used, having the following values :

r, %	0	10	20	30	40
k, tons/sq. in.	12·2	30·5	37·0	41·2	44·0

From the equation on p. 239, the mean yield stress $\bar{k} = 37{\cdot}6$ tons/sq. in.

Initial thickness of strip $h_1 = 0{\cdot}0630$ in.
Pass reduction $r = 40{\cdot}00\%$
Roll force $= 16{\cdot}56 \pm 0{\cdot}50$ tons/in.
Roll torque $= 2{\cdot}37 \pm 0{\cdot}06$ tons-in. per inch width.
$k_2 = 44{\cdot}0$ tons/sq. in.
$\delta = 0{\cdot}4 \times 0{\cdot}0630 = 0{\cdot}0252$ in.
$h_2 = 0{\cdot}0378$ in.
$\delta_2 = 6{\cdot}78 \times 10^{-5}(k_2 - \sigma_2)h_2 = 1{\cdot}16 \times 10^{-4}$ in.

whence :

$$\delta' = 0{\cdot}0253 \text{ in.}$$

$$R' = 4{\cdot}98\left\{1 + \frac{3{\cdot}34 \times 10^{-4} \times 16{\cdot}56}{0{\cdot}0288}\right\} = 5{\cdot}90 \text{ in.}$$

$$P_{e_2} = 5{\cdot}29 \times 10^{-3}\sqrt{5{\cdot}90 \times 0{\cdot}0378}(44{\cdot}0 - \sigma_{e_2})^2$$

By trial and error, σ_{e_2} is found to be $-2{\cdot}31$.

Thus $P_{e_2} = 0{\cdot}794$ tons/in., and P_{e_1} is negligible.

Also, $1 - \dfrac{\sigma_1}{\bar{k}} = 1{\cdot}000$

$$1 - \frac{\sigma_2}{\bar{k}} = 1 + \frac{2{\cdot}31}{37{\cdot}6} = 1{\cdot}061$$

$$\therefore B = \log_e \frac{1{\cdot}061}{1{\cdot}000} = 0{\cdot}0598$$

$$\text{and } a = \mu\sqrt{\frac{R'}{h_2}} = 0{\cdot}055\sqrt{\frac{5{\cdot}90}{0{\cdot}0378}} = 0{\cdot}688.$$

Using Figs. 2*a* and 2*b* of Part I[1] and interpolating for $B = 0{\cdot}0598$ and $a = 0{\cdot}688$ at $r = 40{\cdot}0$:

$f_3 = 1{\cdot}085$ for roll force.

Similarly, using Figs. 4*a* and 4*b* of Part I :

$f_5 = 0{\cdot}519$ for roll torque.

The plastic contribution to the roll force is :

$$P_p = \bar{k}\sqrt{R'\delta}\left(1 - \frac{\sigma_1}{\bar{k}}\right)f_3$$

$$= 37{\cdot}6\sqrt{5{\cdot}90 \times 0{\cdot}0253} \times 1{\cdot}085 = 15{\cdot}71.$$

Thus the total roll force $P = P_p + P_{e_2} = 16{\cdot}50$ tons per inch, and the error is $\dfrac{16{\cdot}50 - 16{\cdot}56}{16{\cdot}56} = -0{\cdot}36\%$.

The roll torque is given by :

$$G = R\bar{k}\delta'\left(1 - \frac{\sigma_1}{\bar{k}}\right)f_5$$

$$= 4{\cdot}98 \times 37{\cdot}6 \times 0{\cdot}0253 \times 0{\cdot}519 = 2{\cdot}44.$$

Thus the roll torque $G = 2{\cdot}44$ tons-in. per inch width, and the error is $\dfrac{2{\cdot}44 - 2{\cdot}37}{2{\cdot}37} = +2{\cdot}9\%$.

The agreement in both cases is very good.

As a further test of the method, two series of passes, in which the pass reduction varied from 4% to 73·9%, have been calculated.* The first set relates to first passes (initial thickness about 0·063 in.) and the second set to second passes (initial thickness about 0·0392 in.), and in both cases no tension was applied. The results are shown in Table I. The roll-force values, with the exception of the 73·9% reduction in a single pass, are all within ± 8% of the corresponding experimental result. The pass of 4·0% on pre-strained material is only − 1·9% in error, whilst, at the other extreme, the 55·8% pass in the same series is only − 4·4% in error. This series has been included in Fig. 1, for comparison.

The roll-torque values are equally good, although there is a slight tendency for the first passes (annealed strip) to be high and the second passes (' prestrained ' strip) to be low. Discounting the pass of 4% reduction, for which the error of the calculated result is less than the expected experimental accuracy, only in two extreme passes is the error greater than 10%.

The results of the tests with various combinations of applied tensions are shown in Tables II and III. Figure 3 shows the distribution of the errors for roll force and torque expressed as the percentage variation of the calculated value from the experimental value, the vertical ordinate being the number of results (out of a total of about 120) falling within that particular unit of error. This graph shows that 95% of the results for roll force fall within ± 10% of the experimental values. The greatest error is 14·1% for a pass on coil 2, where there was a very high front tension with no back tension ; the next largest error (13·1%) was for a single pass of 73·9% reduction. For the errors to be spread equally on the positive and negative sides of the measured values, the coefficient of friction would have to be about 0·057, but the adjustment is hardly justifiable in view of the present knowledge of friction.

On the whole, the calculated torques are slightly high, but (except for coil 3, for which the results are systematically high) 93% of the calculated values lie within ± 10% of the experimental results. The greatest error is + 14·3%.

Tables II and III show that the new approximate

* These experimental results, made available by W. C. F. Hessenberg, are shown in Figs. 1 and 2 of Hessenberg and Sims' paper.[3]

method gives results within ± 10% of the actual results, over the range of the published data. For all practical purposes this is satisfactory. Thus, although the yield-stress curve is reduced to a mean value sometimes differing markedly (*e.g.*, for annealed strip) from the actual yield-stress distribution, no serious error is introduced when calculating roll force and torque. The calculations depend only upon a yield-stress curve and a coefficient of friction; the former can be determined experimentally when necessary, and the latter appear to vary within small limits for normal roll finishes and strip lubricants.

The roll-force values for the tests on prestrained strip are in good agreement throughout, but those for annealed strip are mainly low for 30% reductions and high for 50% reductions. The reason for these systematic variations for annealed material may lie in the yield-stress curves, which differ over the first 30–40% reduction (*see* Table I of Hessenberg and Sims' paper[3]). If the average of these yield-stress curves is taken, there is little difference at higher reductions (*i.e.*, second passes, where agreement is good); but the first passes are brought much closer to the experimental values, because the roll-force values for coil 2 are low where the yield-stress curve is low, and those for coil 3 are high where there is a particularly high yield-stress curve. The main discrepancy, however, is in the values of torque for coil 3 (Table II). Although taking an average yield-stress curve would largely reduce this discrepancy, it appears that the experimental results are uniformly low. The calculated roll-force values, although slightly high for this coil, are not outside the limits (± 10%) indicated by the other tests, yet the calculated torques are definitely higher. The difference is too great to be explained by the observation that the method gives torque values which are generally slightly high—this is a difference of only 2½%, whereas the values for coil 3 are from 10% to 16% too high. The latter are therefore shown dotted in Fig. 3.

The moment of the normal roll pressure is neglected in the torque equation of this paper. Previous calculations[12] show that the torque is overestimated by about 2%. The fact that the calculated torques average about 2½% higher than the experimental values may be attributed to the neglect of this term.

CONCLUSIONS

The method of calculation described gives results, over a wide range of pass reductions, strip tensions, and yield-stress values, essentially within ± 10% of the measured results. For practical purposes this degree of accuracy is satisfactory, and it appears that greater elaboration is not worth while. (The rolling speed, lubricant, and roll diameter were not varied.)

The approximations and assumptions made in the derivation of the equations for roll force and torque, upon which the non-dimensional graphs for functions f_3 and f_5 are based, are found to cause no serious error.

Discrepancies of up to ± 20% previously found between the calculated and experimental values have been shown to arise from the neglect of the elastic contribution to the roll force and torque. When this is allowed for, the coefficient of friction, which normally has a value rather smaller than that required for the best quantitative fit of the calculated and measured values, then conforms. Hessenberg and Sims' conclusion that a higher coefficient is needed for passes on prestrained material (Figs. 2 and 3 of their paper[3]) can be explained when the elastic effects are considered.

The discrepancy found by Bland and Ford in their theory for those first passes on annealed strip for which a high back tension is applied does not arise in this approximate method, because a mean yield stress is used. The tabulated results show no tendency for the calculated values to be low in these passes.

Part III—AN APPROXIMATE TREATMENT OF THE ELASTIC COMPRESSION OF THE STRIP IN COLD ROLLING

By D. R. Bland, M.A., and H. Ford, D.Sc.(Eng.), Ph.D, M.I.Mech.E.

SYNOPSIS

Approximate equations are derived for the contributions to the roll force and torque from those parts of the roll gap in which the strip is only elastically compressed.

In cold rolling, the strip passes through three zones. In the first zone, near the plane of entry to the roll gap, the strip is elastically compressed until the yield stress is reached; in the second zone it is further compressed plastically, and in the third it recovers elastically. The first and third processes are reversible, and the second is irreversible. The boundaries of the three zones are not known exactly, but the simplest approximation is that shown in Fig. 2 of part II.

None of the theories of rolling, nor the calculations of roll force and torque, have previously taken into account the effect of the elastic zones. Only the contribution of the plastic zone has been considered, the elastic effects having been assumed to be negligible. It has, however, been recognized that for small reductions—say 10% or less—the zone of elastic recovery

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might be important, and that for very small reductions —of the order of 2% or less—the zone of initial elastic compression may also be significant.

This paper puts forward an approximate assessment of the influence and nature of the zones of elastic compression and recovery, and presents a method for computing their contribution to the roll force and torque.

ASSUMPTIONS MADE IN PART III

The elastic zones on the entry and exit sides of the roll gap not only contribute to the roll force directly but also apply horizontal compressive stresses to the section of the strip in the plastic arc, thus indirectly augmenting the roll force. In addition, the radius of the flattened arc of contact is modified.

The solution put forward in the following pages assumes the simplest distribution of the various zones shown in Fig. 2, with plane strain existing throughout. The plastic zone is assumed to be of the shape shown in this Figure in all theories of rolling,* with constant vertical and horizontal stresses and zero shearing stress across any vertical cross-section. It follows, therefore, that the vertical and horizontal stresses are constant on the cross-sections at the plastic–elastic boundaries, and that the shearing stresses are zero. For the elastic zone, only two boundary conditions are necessary. The problem is therefore overdetermined. The existence of the three conditions arises from the necessity of making approximations to obtain any result in the plastic zone. To satisfy the equations of equilibrium at the boundary, the shearing stress and horizontal stress must be continuous. The continuity of the vertical stress is not postulated; this means that the yield criterion will not be satisfied exactly on both sides of the boundary. The most satisfactory solution is to postulate that the mean vertical stress on the elastic side of the boundary, taken with the horizontal and zero shear stress, satisfies the yield criterion.

In the plastic zone, the vertical and horizontal stresses $\widehat{yy}$ and $\widehat{xx}$ satisfy the yield criterion

$$\widehat{xx} - \widehat{yy} = -k.$$

The same yield criterion is taken at the plastic–elastic boundary, with $\widehat{yy}$ replaced by the mean vertical stress at the boundary. This amounts to taking Poisson's ratio $\nu = 0{\cdot}5$ in the yield criterion, instead of its true value of about $0{\cdot}3$; in other words, the third principal stress (that in the direction of plane strain) is assumed to be discontinuous in that it jumps from the elastic value of $\nu(\widehat{xx} + \widehat{yy})$ to its plastic value of $\frac{1}{2}(\widehat{xx} + \widehat{yy})$.† These discontinuities exist because the elastic component of strain is neglected in the plastic region. Until theory advances sufficiently to take this component into account, an approximation of the type described above will continue to be necessary. The same approximation is made in the conventional engineering treatment of the bending of a beam in plane strain.

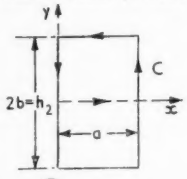
The elastic zones in Fig. 2 have been drawn to begin at the points where the strip enters or leaves the roll gap. This assumption neglects any effect the strip outside the roll gap might have on the elastic zone. It is shown on p. 247 that this leads to an underestimate of the contribution of the elastic zone to the roll force. The stress acting on the elastic zone along its boundary at the outside of the gap is simply that due to the applied tension. (In practice, there are some residual stresses left in the strip; however, their resultant is zero.)

On the upper and lower surfaces of the elastic zones the normal displacement is known, since the strip is in contact with the rolls. The other boundary condition is zero shearing stress on the surface. This is a valid approximation, because the coefficient of friction in rolling is about 0·05.* However, the effect of friction is taken into account in calculating both the effective tensions at the beginning of the plastic zones and the contribution from the elastic zones to the torque.

To sum up, the elastic zones are approximately rectangular. The shearing stress is zero on all boundaries. The normal stress is a constant equal to the applied tension, on the vertical sides, and the normal displacement is specified on the upper and lower surfaces. The problem is to calculate the total normal force on the upper or lower surfaces.

THE ELASTIC RECOVERY ZONE

The adjacent figure shows a cross-section (a rectangle of width a and height $2b = h_2$) of the assumed elastic recovery zone. The axes are taken as shown. The boundary conditions for the upper half cross-section are:



Along $x = 0$ and $x = a$, $\widehat{xx} = \sigma_2$, $\widehat{xy} = 0$

Along $y = b$,

$$v = -\frac{\nu(1+\nu)}{E} b\sigma_2 - \frac{1}{2R'}(a^2 - x^2), \quad \widehat{xy} = 0 \ldots\ldots(1)$$

and along $y = 0$, by symmetry, $v = 0$ and $\widehat{xy} = 0$.

A relationship is required for the compressive force

$$P_{e_2} = -\left(\int_0^a \widehat{yy}\,dx\right)_{y=b}$$

in terms of the known displacement v along $y = b$.

Consider $\left(\int_0^a v\,dx\right)_{y=b}$. Since $\left(\int_0^a v\,dx\right)_{y=0} = 0$,

$$\left(\int_0^a v\,dx\right)_{y=b} = -\int_C v\,dx,$$ the boundary circuit C being described in the sense shown.

$$= \int_0^a \int_0^b \frac{\partial v}{\partial y}\,dx\,dy, \quad \text{by Green's lemma.}$$

* With the exception of Orowan's 'exact' theory, which uses a different but not necessarily better set of assumptions.

† The authors thank Dr. R. Hill for drawing their attention to this discontinuity.

* If the effective tension at the beginning of the plastic zone is used in the elastic zone, instead of the applied tension, the increase in the compressive force in the elastic zone is about 8%. This overestimates the effect of the surface friction.

$$\therefore \left(\int_0^a v dx\right)_{y=b} = \int_0^a\int_0^b e_{yy}\,dxdy. \quad \text{by definition of } e_{yy}.$$

$$= \int_0^a\int_0^b \left(\frac{1-\nu^2}{E}\widehat{yy} - \frac{\nu(1+\nu)}{E}\widehat{xx}\right)dxdy,$$

by the generalized Hooke's law in plane strain.

$$= \frac{1-\nu^2}{E}\int_0^a\int_0^b \widehat{yy}\,dxdy - \frac{\nu(1+\nu)}{E}\int_0^a\int_0^b \widehat{xx}\,dxdy$$

$$= \frac{1-\nu^2}{E}b\left(\int_0^a \widehat{yy}dx\right)_{y=b} - \frac{1-\nu^2}{E}\int_0^a\int_0^b y\frac{\partial\widehat{yy}}{\partial y}\,dxdy$$

$$- \frac{\nu(1+\nu)}{E}ab\sigma_2 + \frac{\nu(1+\nu)}{E}\int_0^a\int_0^b x\frac{\partial\widehat{xx}}{\partial x}\,dxdy \quad \ldots(2)$$

on integrating by parts, the first term with respect to y, the recond term with respect to x.

Since $\widehat{xy} = 0$ on all boundaries,

$$\int_C y\widehat{xy}dy = 0, \quad \int_C x\widehat{xy}dx = 0.$$

Therefore, by Green's lemma,

$$\int_0^a\int_0^b y\frac{\partial\widehat{xy}}{\partial x}\,dxdy = 0, \quad \int_0^a\int_0^b x\frac{\partial\widehat{xy}}{\partial y}\,dxdy = 0$$

and hence, by the equilibrium equations,

$$\int_0^a\int_0^b y\frac{\partial\widehat{yy}}{\partial y}\,dxdy = 0, \quad \int_0^a\int_0^b x\frac{\partial\widehat{xx}}{\partial x}\,dxdy = 0.$$

Substituting in equation (2):

$$\left(\int_0^a v dx\right)_{y=b} = \frac{1-\nu^2}{E}b\left(\int_0^a \widehat{yy}dx\right)_{y=b} - \frac{\nu(1+\nu)}{E}ab\sigma_2 \quad \ldots(3)$$

Substituting from equation (1), using the expression for P_{e_2}:

$$-\frac{\nu(1+\nu)}{E}ab\sigma_2 - \frac{1}{3R'}a^3 = -\frac{1-\nu^2}{E}bP_{e_2} - \frac{\nu(1+\nu)}{E}ab\sigma_2$$

whence $$P_{e_2} = \frac{Ea^3}{3(1-\nu^2)R'b} = \frac{2Ea^3}{3(1-\nu^2)R'h_2} \quad \ldots\ldots(4)$$

It can be seen from equation (3) that if the elastic recovery of the strip outside the assumed zone is neglected, the value of P_e is underestimated, and the term $\int_0^a v dx$ would be replaced by $\int_0^\infty v dx$. The latter integral is greater in absolute value, not only because it includes the range of integration of the former but also because the integrand is arithmetically greater at points near to and less than $x = a$.

To determine the value of a, use is made of the fact that at $x = 0$ the strip is plastic. This gives:

$$\sigma_2 - Y = k \quad \ldots\ldots(5)$$

where Y is the mean value of $\widehat{yy}$ across the section $x = 0$. In the plastic zone, homogeneous compression is assumed and a mean value of $\widehat{yy}$ is used in the equilibrium equation. At $x = 0$ the mean value of $\widehat{yy}$ is given by:

$$Y = \frac{1}{b}\left(\int_0^b \widehat{yy}dy\right)_{x=0}$$

$$\therefore \quad Y = \frac{1}{b}\left\{\int_0^b \left(\frac{E}{1-\nu^2}e_{yy} + \frac{\nu}{1-\nu}\widehat{xx}\right)dy\right\}_{x=0}$$

$$= \frac{E}{b(1-\nu^2)}\left(\int_0^b \frac{\partial v}{\partial y}\,dy\right)_{x=0} + \frac{\nu}{b(1-\nu)}\sigma_2 b,$$

since $\widehat{xx} = \sigma_2$ at $x = 0$.

Now $$dv = \frac{\partial v}{\partial x}dx + \frac{\partial v}{\partial y}dy = \frac{\partial v}{\partial y}dy \text{ on } x = 0.$$

Therefore $$Y = \frac{E}{b(1-\nu^2)}(v)_{x=0,\,y=b} + \frac{\nu\sigma_2}{1-\nu}$$

and since $$(v)_{x=0,\,y=b} = -\frac{\nu(1+\nu)}{E}b\sigma_2 - \frac{a^2}{2R'},$$

$$Y = -\frac{a^2E}{2b(1-\nu^2)R'}.$$

Substituting in equation (5):

$$k - \sigma_2 = \frac{a^2E}{2b(1-\nu^2)R'}$$

$$\therefore \quad a^2 = \frac{2b(1-\nu^2)R'(k-\sigma_2)}{E}$$

$$= \frac{h_2R'}{E}(1-\nu^2)(k-\sigma_2).$$

Hence, substituting in equation (4):

$$P_{e_2} = \tfrac{2}{3}(k-\sigma_2)\sqrt{\frac{h_2R'}{E}(1-\nu^2)(k-\sigma_2)} \quad \ldots\ldots(6)$$

If h_m is the minimum thickness of the strip in the pass,

$$h_2 - h_m = -2(v)_{x=0,\,y=b}$$

$$= \frac{\nu(1+\nu)}{E}h_2\sigma_2 + \frac{a^2}{R'}$$

$$= \frac{\nu(1+\nu)}{E}h_2\sigma_2 + \frac{h_2(1-\nu^2)(k-\sigma_2)}{E} \quad \ldots\ldots(7)$$

Here h_2 is the strip thickness when the tension has been released. If it is taken as the thickness as the strip leaves the roll gap, then the first term on the right-hand side of equation (7) is omitted. This latter thickness is denoted later in the paper by h_e.

Equation (6) gives the value of P_{e_2}, the contribution to the roll force from the zone of elastic recovery. The zone also contributes to the torque and to the effective horizontal pressure at the minimum thickness. The effect of friction cannot be neglected for these contributions. Except when high back tensions are applied, the strip in this zone is moving faster than the roll surface, so applying a torque to the roll and helping it to turn. Such a torque is, by convention, considered negative. Its value, if μ is the coefficient of friction, is:

$$G_{e_2} = -R\int_0^{\theta_2} \mu s R'd\theta$$

$$\therefore \quad G_{e_2} = -\mu R P_{e_2} \quad \ldots\ldots(8)$$

The total horizontal force applied to both roll surfaces is $2\mu P_{e_2}$. Over a section of thickness h_2 this force is equivalent to a pressure $2\mu P_{e_2}/h_2$, and the effective front tension at the beginning of the plastic zone is therefore

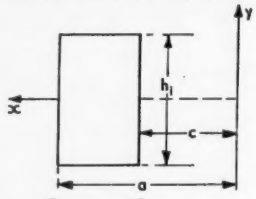
$$\sigma_2' = \sigma_2 - \frac{2\mu P_{e_2}}{h_2}.$$

The sign of the second term is negative since it is a compressive stress, the roll holding the strip

back in this zone. Thus σ_2' is the value of front tension that should be used for calculations in the plastic zone.

THE INITIAL ELASTIC COMPRESSION ZONE

The analysis is similar to that for the recovery zone. The cross-sectional rectangle (*see* diagram) is now bounded by $x = c$ and $x = a$. At $x = c$ the strip enters the roll gap; at $x = a$ the plastic zone commences. The boundary conditions are:



Along $x = c$ and $x = a$, $\widehat{xx} = \sigma_1$, $\widehat{xy} = 0$

Along $y = b$, $v = -\frac{\nu(1+\nu)}{E} b\sigma_1 - \frac{1}{2R'}(a^2 - x^2)$ ...(9)

and along $y = 0$, by symmetry, $v = 0$ and $\widehat{xy} = 0$.

To correspond with equation (3):

$$\left(\int_c^a v\,dx\right)_{y=b} = \frac{1-\nu^2}{E} b\left(\int_c^a \widehat{yy}\,dx\right)_{y=b} - \frac{\nu(1+\nu)}{E}(a-c)b\sigma_1$$

Now

$$\left(\int_c^a v\,dx\right)_{y=b} = \int_c^a \left\{-\frac{\nu(1+\nu)}{E} b\sigma_1 - \frac{1}{2R'}(a^2 - x^2)\right\} dx,$$

from equation (9).

$$= -\frac{\nu(1+\nu)}{E} b(a-c)\sigma_1 - \frac{1}{2R'}\left\{a^2(a-c) - \tfrac{1}{3}(a^3 - c^3)\right\}$$

$$\therefore P_{e_1} = -\left(\int_c^a \widehat{yy}\,dx\right)_{y=b}$$

$$= \frac{E}{2(1-\nu^2)R'b}\left\{a^2(a-c) - \tfrac{1}{3}(a^3 - c^3)\right\}$$

$$= \frac{E}{(1-\nu^2)R'h_1}\left\{a^2(a-c) - \tfrac{1}{3}(a^3 - c^3)\right\} \quad ...(10)$$

As before,

$$\sigma_1 - Y = k$$

and $$Y = \frac{E}{b(1-\nu^2)}(v)_{x=c,\ y=b} + \frac{\nu\sigma_1}{1-\nu}$$

Now $$(v)_{x=c,\ y=b} = -\frac{\nu(1+\nu)}{E} b\sigma_1 - \frac{1}{2R'}(a^2 - c^2),$$

from equation (9).

Therefore

$$\sigma_1 - k = Y = -\frac{E(a^2 - c^2)}{2bR'(1-\nu^2)}$$

i.e., $$a^2 - c^2 = \frac{h_1 R'(1-\nu^2)}{E}(k - \sigma_1) \quad .....(11)$$

The length of the arc of contact from the position of minimum thickness h_m to entry $= a = \sqrt{R'(h_1 - h_m)}$.

Therefore $$a^2 = R'(h_1 - h_2) + R'(h_2 - h_m) \quad .....(12)$$

The value of $h_2 - h_m$ is found from the conditions in the elastic recovery zone, *i.e.*, from equation (7). Thus equation (12) gives a, (11) gives c, and (10) gives P_{e_1}.

However, for passes in which the reduction is greater than 4%, neglecting the term $h_2 - h_m$ gives an error of less than 6%. For such passes the term $a - c$ can be neglected in comparison with a or c. Then, from equation (10):

$$P_{e_1} = \frac{E}{(1-\nu^2)R'h_1}\left\{(a-c)\tfrac{1}{3}(2a^2 - ac - c^2)\right\}$$

$$= \frac{E}{(1-\nu^2)R'h_1}\left\{(a-c)^2\tfrac{1}{3}(2a + c)\right\}$$

$$\simeq \frac{E}{(1-\nu^2)R'h_1} a(a-c)^2$$

Now $$a^2 - c^2 \simeq 2a(a-c).$$

Therefore, from equation (11),

$$a - c = \frac{h_1 R'(1-\nu^2)}{2aE}(k - \sigma_1)$$

and from equation (12),

$$a \simeq \sqrt{R'(h_1 - h_2)}$$

Hence

$$P_{e_1} \simeq \frac{E}{(1-\nu^2)R'h_1} \cdot \frac{h_1^2 R'^2 (1-\nu^2)^2}{4E^2}(k - \sigma_1)^2 \cdot \frac{1}{\sqrt{R'(h_1 - h_2)}}$$

$$= \frac{(1-\nu^2)h_1}{4}\sqrt{\frac{R'}{h_1 - h_2}}\frac{(k-\sigma_1)^2}{E} \quad .....(13)$$

This is the contribution to the roll force from the zone of initial elastic compression for reductions exceeding 4%. The contribution to the torque is

$$G_{e_1} = \mu R P_{e_1} \quad .....(14)$$

The new effective back tension is

$$\sigma_1' = \sigma_1 - \frac{2\mu P_{e_1}}{h_1} \quad .....(15)$$

ROLL FLATTENING

If the stress distribution on any cross-section of a right circular cylinder normal to its axis is the half ellipse cut off by either of its principal axes, then the decrease in curvature caused by the stress distribution over that part of the surface where it is applied is:

$$\delta K = \frac{4(1-\nu^2)P}{E\pi d^2} \quad .....(16)$$

where P is the load per unit width and d is the length of the semi-axis on which the half ellipse 'stands.'[11] This is a consequence of the Hertz theory of elastic contact. Let R and R' be the radii of the undeformed cylindrical surfaces. Then:

$$\frac{1}{R'} = \frac{1}{R} - \frac{4(1-\nu^2)P}{E\pi d^2} \quad .....(17)$$

Hitchcock[10] assumed that P could be taken as the roll force per unit width in rolling, *i.e.*, he assumed that the actual normal stress distribution could be replaced by an elliptical one on the same base and of the same area. The length of the arc of contact remains equal to $2d$. In an analysis made by Bland[12] without this assumption, it was concluded that although the shape of the deformed roll surface was not circular, the values of roll force calculated with the aid of Hitchcock's formula fell within the range of possible error of the more accurate solution. In equation (17), therefore, P is taken as the actual roll force.

The lengths of the arc of contact from entry to the point of minimum thickness and from the point of minimum thickness to exit are $\sqrt{R'(h_i - h_m)}$ and

$\sqrt{R'(h_e - h_m)}$, respectively, where h_i, h_m, and h_e are the thicknesses at entry, minimum, and exit, respectively. Therefore

$$2d = \sqrt{R'(h_i - h_m)} + \sqrt{R'(h_e - h_m)}.$$

Now

$$h_i - h_m = (h_1 - h_2) - (h_1 - h_i) + (h_2 - h_e) + (h_e - h_m)$$
$$= \delta + \delta_2 + \delta_t,$$

where

$$\left.\begin{aligned} \delta &= \text{draft} = h_1 - h_2 \\ \delta_2 &= h_e - h_m = \frac{h_2(1 - \nu^2)}{E}(k_2 - \sigma_2), \\ &\qquad \text{from equation (7)} \\ \delta_t &= \frac{\nu(1 + \nu)}{E}(h_2\sigma_2 - h_1\sigma_1). \end{aligned}\right\} \quad \ldots\ldots(18)$$

Hence

$$2d = \sqrt{R'(\delta + \delta_2 + \delta_t)} + \sqrt{R'\delta_2}$$
$$= \sqrt{R'}\left\{\sqrt{\delta + \delta_2 + \delta_t} + \sqrt{\delta_2}\right\}.$$

Substituting for d^2 in equation (17) :

$$\frac{1}{R'} = \frac{1}{R} - \frac{16(1 - \nu^2)P}{E\pi R'\left\{\sqrt{\delta + \delta_2 + \delta_t} + \sqrt{\delta_2}\right\}^2}$$

Therefore

$$R' = R\left\{1 + \frac{16(1 - \nu^2)P}{E\pi\left\{\sqrt{\delta + \delta_2 + \delta_t} + \sqrt{\delta_2}\right\}^2}\right\} \quad \ldots(19)$$

Equation (19) is the equation for R', the terms δ, δ_2, and δ_t being given by equation (18). When the elastic recovery is neglected, $\delta_2 = \delta_t = 0$ and equation (19) reduces to the well-known form :

$$R' = R\left\{1 + 16\,\frac{(1 - \nu^2)}{\pi E} \cdot \frac{P}{\delta}\right\} \quad \ldots\ldots\ldots\ldots(20)$$

CONCLUSIONS

Equations (6), (8), (9), (13)–(15), and (19), are used in Part II to evaluate the effect of the elastic zones on roll force and torque. It has been shown there that this leads to values of these quantities which are in much better agreement with the experimental values, the maximum errors being reduced, in more than 95% of the results, from $\pm$ 20% to $\pm$ 10%.

In Part III it has been shown that the elastic zones have an appreciable effect on the total roll force and torque. The assumptions made indicate the difficulties that must be overcome to obtain a more accurate solution. The equations of the plastic zone must be solved more accurately ; this solution may need to take into account the elastic component of strain in that zone.

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The Rapid Softening of Cold-Drawn Austenitic Stainless Steels

By F. A. Hodierne, B.Sc., A.I.M., and C. E. Homer, B.Sc., Ph.D., F.I.M.

SYNOPSIS

The work was undertaken to provide the metallurgical basis for the rapid softening of cold-drawn austenitic stainless-steel tubes. Tubes of five different steels were obtained in the cold-drawn condition, and strips cut from them were heated for a few seconds to temperatures between 500° and 1350° C. For comparison, other strips were heated for 5 minutes. A detailed study has been made of the properties and structure of all specimens. The cold-drawn steels can be softened satisfactorily by heating for 5–6 seconds to temperatures slightly higher than those recommended for ordinary times of heating. The properties and structure are the same as those in specimens heated for a longer time.

RAPID methods of heating have been used in heat-treatment operations, but there is little published information on the effects of very short times of heating on the properties and structure of steels. The present research was initiated to provide a basis for

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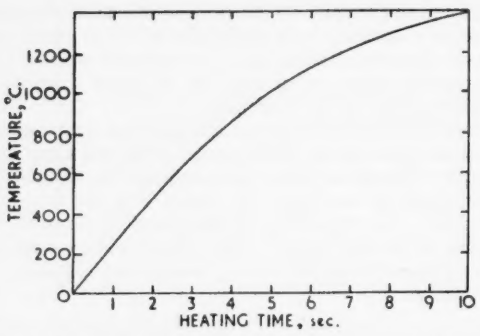

Fig. 1—Heating curve for rapid heating experiments

applying induction heating to the softening of cold-drawn stainless-steel tubes.

The effects of short times of heating on five austenitic stainless steels have been studied, and heat-treatment conditions for the use of high-speed methods of heating are recommended. The way in which the properties and structure of the steels depend upon the heat-treatment in the range of 500–1350° C. was investigated. The very high temperatures were included in case such treatment might be needed to ensure full softening of the material in the short time available, and to show by how much temperature fluctuations might affect the results.

PROGRAMME OF INVESTIGATION

Strips cut from tubes finished to the same size with similar cold-drawing passes were heated in a few seconds and immediately quenched in water. Similar strips were heated in a furnace for 5 min. and also water-quenched. These were used for hardness tests, microscopic examination, magnetic tests for determining the proportion of ferrite, and intercrystalline corrosion tests.

MATERIALS

The materials comprised one cold-drawn tube of each steel, 1½ in. outside dia. × 16 S.W.G. All except one were drawn to the finished size from 1¾ in. outside dia. × 12 S.W.G. in three passes without intermediate annealing, a reduction in area of 46%. The tube made from the straight 18/8 steel was drawn from 1¾ in. × 13 S.W.G., a reduction in area of 40%. The analyses of the tubes were as follows:

Steel No.	C, %	Si, %	Mn, %	Cr, %	Ni, %	Mo, %	Ti, %	Nb, %
1	0·115	0·52	0·41	18·93	8·90	0·11	0·018	Nil
2	0·10	0·77	0·28	18·58	8·79	0·09	0·87	Nil
3	0·070	0·24	0·41	18·38	8·42	2·78	0·02	Nil
4	0·10	0·53	0·76	18·55	12·73	Trace	0·022	1·05
5	0·079	1·49	0·78	24·61	20·90	0·06	0·02	Nil

EXPERIMENTAL TECHNIQUE

Heat-Treatment

For the rapid-heating experiments, strips 8 in. × 0·1 in., cut longitudinally from the tubes, were heated to the required temperature by passing a heavy current through them, and were immediately quenched. During the experiments, each specimen was held at both ends by heavy copper clamps connected to a 10-V. supply from a transformer, 1 in. being held in each clamp. The temperature was measured on a high-speed recorder by a fine Pt/Pt–Rh thermocouple spot-welded to the specimen. The heating current was switched off when the required temperature was reached, and at the same time the specimen was quenched in a small tank of water brought up automatically from beneath. The rate of heating employed in all these experiments is shown in Fig. 1.

Preliminary experiments showed that the centre 5-in. part of the strip was at a uniform temperature. The couple was therefore welded to the specimen 1½ in. from one clamp, and, after heating, a 3-in. length was taken from the centre of the strip for testing. Of this, a 2-in. length was used for magnetic determination of the ferrite content, and subsequently for the intercrystalline corrosion test, and the remainder was used for hardness tests and micro-examination, the short length affected by the spot welding being discarded.

The strips heated for 5 min. were 3 in. × 0·1 in., cut longitudinally from the tubes. They were heated in a small electric furnace, and preliminary tests with a thermocouple welded to a specimen showed that the time of heating to the different temperatures was about 1 min. in each case.

Determination of Ferrite Content

Although the magnetic method of ferrite determination is probably not highly accurate, it was considered to be satisfactory for the present purpose. The ferrite contents were therefore determined by the magnetic apparatus shown in Fig. 2, which consists of two Tufnol tubes, 5 in. long by ½-in. bore, on which are primary windings, each consisting of 108 turns of 22 S.W.G. glass-covered wire. Short secondary coils, consisting of 1000 turns of 40 S.W.G. enamel-covered wire, are wound over the primary coils at the centre of their length. The primary windings are fed with a current of 2 amp. from a 4-V. 50-cycle A.C. supply. The voltages induced in the secondary windings are opposed, and normally cancel out each other. When a specimen is inserted in one of the coils, the balance is disturbed, and an e.m.f. is produced, whose magnitude is related to the permeability of the specimen, and hence to its ferrite content. This e.m.f. is measured by a sensitive valve voltmeter, with 11 ranges. As it is not possible to calculate the ferrite content, the apparatus is calibrated with specimens of known ferrite content. Smith and Bowen[1] having shown that the use of pure iron instead of an alloyed ferrite in calibrating an apparatus for this purpose introduces no serious error, it was decided to make

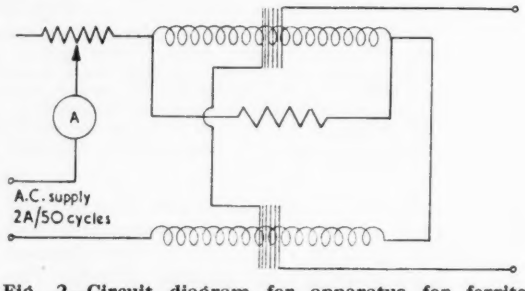

Fig. 2—Circuit diagram for apparatus for ferrite determination

the standards from iron and tin powders mixed in different proportions. The mixtures were compressed to form compacts of the same size as the steel specimens.

Before testing, the specimens were pickled to remove scale, since preliminary tests indicated that in some cases the presence of scale gave ferrite values that were too high.

Intercrystalline Corrosion Test

The test described by Rosenberg and Darr[2] was chosen as being more severe than the 'weld decay' tests mentioned in most specifications. The descaled specimens were boiled for seven periods of 48 hr. in a solution of 100 g. of copper sulphate ($CuSO_4.5H_2O$), 100 ml. of concentrated sulphuric acid, and 900 ml. of water. The specimens were examined after each period, and any that had obviously been attacked were removed; the test was then continued using fresh solution. This test was applied to all specimens after heat-treatment, but without additional sensitizing treatment at 650° C.

RESULTS

Hardness

The results of diamond-hardness tests on the five steels after rapid heating and after 5 min. heating are given in Figs. 3*a–e*. All the steels begin to soften at about 600° C.; between 800–1000° C. the degree of softening increases rapidly with rise in temperature. At 1000° C. the hardness approaches the minimum figure obtainable on the material in question, and further rise in temperature has a smaller effect. With some of the steels minimum hardness is obtained at about 1150° C., but others show a slight fall with rising temperature up to the highest temperature used. For most temperatures there is little difference between the effects of the shorter and longer times of heating, although the longer time usually gives slightly lower hardness figures. In the range 800–900° C., however, time of heating has a marked effect on final hardness.

The curves for steels 2 (18/8/Ti), 3 (18/8/Mo), and 5 (25/20) show effects not seen on the curves for steels 1 (18/8) and 4 (18/13/Nb). The hardness after heating at about 600° C. is greater than that in the drawn condition. Steels 2 and 3 also have a slightly increased hardness after treatment above 1200° C.

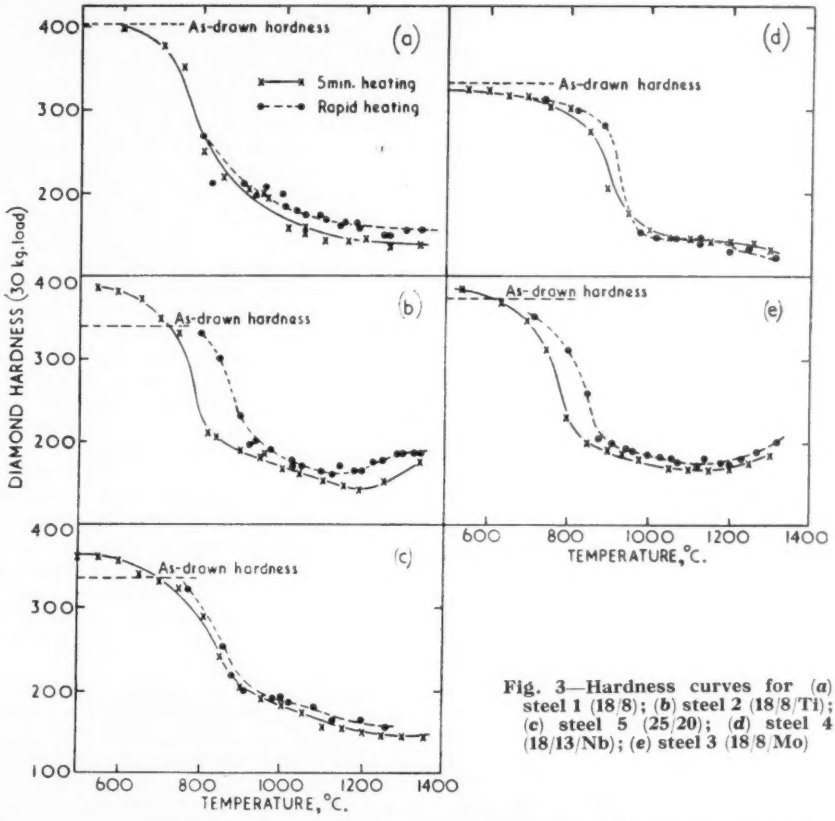

Fig. 3—Hardness curves for (*a*) steel 1 (18/8); (*b*) steel 2 (18/8/Ti); (*c*) steel 5 (25/20); (*d*) steel 4 (18/13/Nb); (*e*) steel 3 (18/8/Mo)

Ferrite Content

The ferrite contents of steels 1, 2, and 3 after treatment at different temperatures are shown in Figs. 4*a–c*. Steel 1 has a small percentage of ferrite in the cold-drawn condition, which falls to a negligible value after heating between 900° and 1200° C.; above 1200° C. the curve rises sharply.

Steels 2 and 3 have much higher ferrite contents in the cold-drawn condition, which decrease to a minimum after heating between 800° and 900° C. The

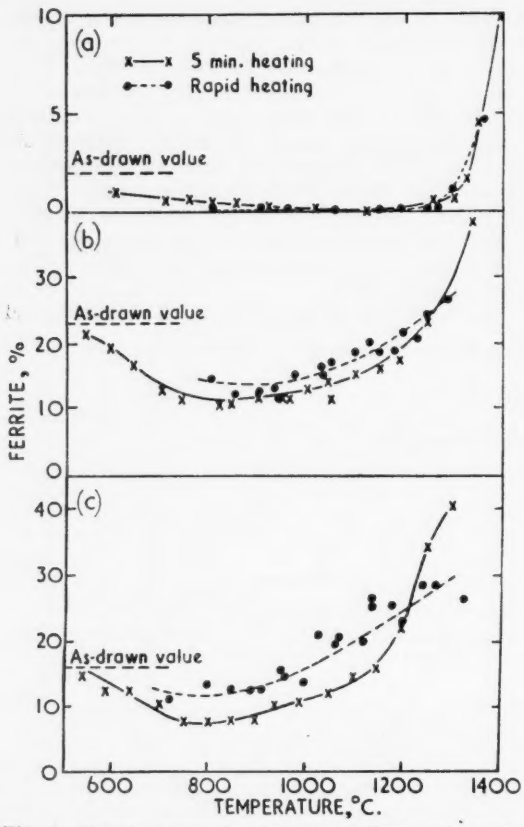

Fig. 4—Ferrite curves for (*a*) steel 1 (18/8); (*b*) steel 2 (18/8/Ti); (*c*) steel 3 (18/8/Mo)

proportion of ferrite increases rapidly above 1150° C. The specimens heated rapidly show a smaller decrease in ferrite content at 800–900° C. and a smaller increase at high temperatures than corresponding specimens heated for 5 min.

No ferrite was detected in steels 4 and 5 either in the cold-drawn condition or after heating up to 1350° C.

Intercrystalline Corrosion

The severe intercrystalline corrosion test affected few of the specimens. Those affected were all of steel 1 (18/8), which had either been rapidly heated below 800° C. or heated for 5 min. below 700° C.

Microstructure

Microscopic examination helped to explain some of the effects shown by the hardness and ferrite curves, and to decide what rapid heat-treatment conditions should be recommended for large-scale trials. The specimens were generally etched electrolytically in 10% oxalic acid, but a few specimens of the 25/20 steel were etched in a solution of 5 g. of ferric chloride ($FeCl_3.6H_2O$), 50 ml. of hydrochloric acid, and 100 ml. of methylated spirit, which was found to be better for revealing grain boundaries in this material.

With heat-treatment temperatures up to about 1100° C., the three 18/8 steels (1, 2, and 3) behave similarly, showing similar changes in microstructure. Figures 5*a–f* show the effects of rapid heating to different temperatures on the structure of steel 1 (18/8). In the 18/8 steels cold-work causes a breakdown of the austenite, particularly at grain boundaries and slip planes. The ferrite curves (Figs. 4*a–c*) show quantitatively that these steels contain more ferrite in the cold-worked condition than after the usual softening treatment; Fig. 5*a* shows a typical microstructure of the cold-worked material. The precipitated ferrite progressively dissolves in the austenite as the temperature is raised above 500° C. Further precipitation appears to occur simultaneously in the positions occupied by the ferrite (Fig. 5*b*), at which stage steels 2 and 3 (Fig. 6*a*) as well as steel 1 can readily be etched to show this effect without pitting the δ-ferrite. This precipitate consists mainly of carbide, but some σ may be present as well. The presence or absence of σ could not be established directly, but it is significant that the minimum ferrite content in steels 2 and 3 occurs at a temperature at which σ is formed most readily.[1, 3] Observations in other investigations support the idea that some σ is formed in steel 3, if not in steel 2.

Re-solution of the precipitate seems to begin above 700° C. in steel 1, continuing up to 1000–1050° C. The disappearance of the precipitate coincides approximately with the recrystallization of the austenite (Figs. 5*c* and *d*) and the approach to complete softening of the steel. Recrystallization is complete at 1090° C. (Fig. 5*e*), but the grain size is rather small, a larger and more normal grain size being obtained at 1140° C. (Fig. 5*f*).

When the specimens are heated for 5 min. the same series of changes occurs, but the extent to which the effects are observed at a particular temperature naturally varies with the time of heating. A longer time appears to increase the amount of precipitation in the range 550–920° C. (Fig. 7*a*), but enables the precipitate to be redissolved at a lower temperature, *i.e.*, 950–1000° C. Recrystallization also takes place at a somewhat lower temperature, and full softening with a normal grain size is obtained at 1050° C. (Fig. 7*b*).

Steels 2 and 3 show the same effects at about the same temperatures as steel 1, both with rapid heating and with 5 min. heating. Fig. 8 shows the structure of steel 3 after rapid heating to 1120° C.

The cause of the slight hardening when steels 2 and 3 are heated below 650° C. after cold-working is not apparent from the microstructures, but must be associated with a precipitation effect.

The increasing formation of ferrite above 1150° C. is not evident in the microstructure of steel 1, probably because of the small quantities involved; the only noticeable effect of high temperature on this steel is an increase in grain size. With steels 2 and 3 the increase in ferrite content is large, occurring to a greater extent with the longer time of heating. At first the new ferrite is deposited on the existing stringers, but at 1350° C. with 5 min. heating the ferrite takes the form of equi-axed grains (Fig. 6*b*). The specimens heated for 5 min. between 1150° C. and 1300° C. show slight coring, indicating that they have not reached equilibrium; in the rapidly heated specimens this is very marked.

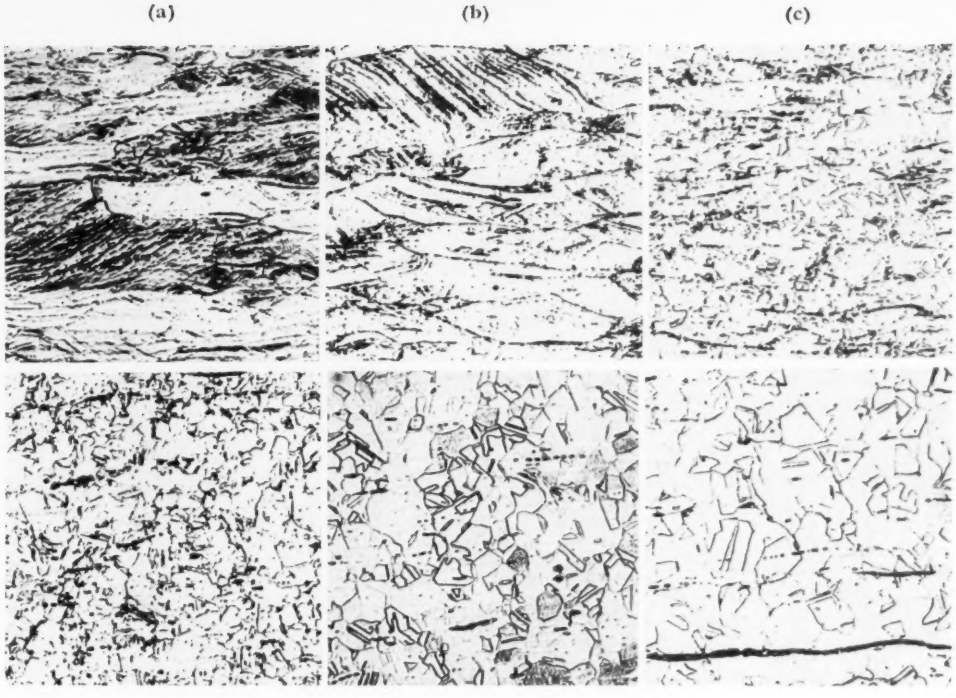

Fig. 5—Steel 1 (18/8): (*a*) Cold-drawn ; (*b*) rapidly heated to 800° C. ; (*c*) to 950° C. ; (*d*) to 1030° C. ; (*e*) to 1090° C. ; (*f*) to 1140° C. All etched in oxalic acid × 200

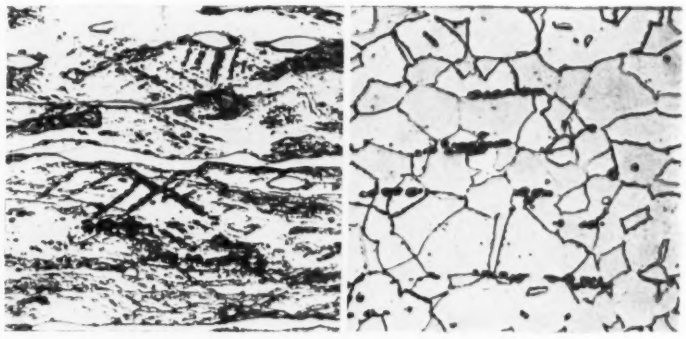

Fig. 6—Steel 2 (18/8/Ti) : (*a*) Rapidly heated to 800° C. (× 750) (*b*) heated for 5 min. at 1350° C. (× 400). Etched in oxalic acid.

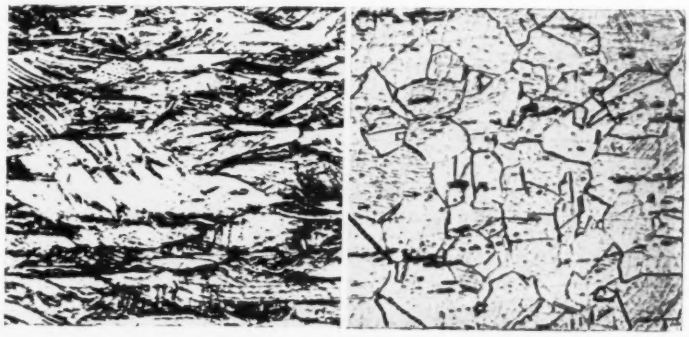

Fig. 7—Steel 1 (18/8) : Heated for 5 min. at (*a*) 750° C. ; (*b*) 1050° C. Etched in oxalic acid × 200

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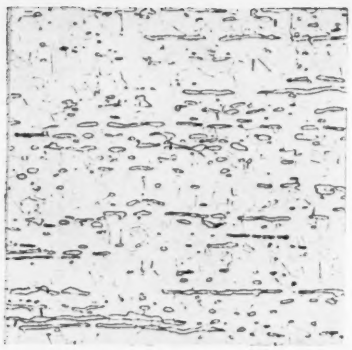

Fig. 8—Steel 3 (18/8/Mo) rapidly heated to 1120° C. Etched in oxalic acid × 200

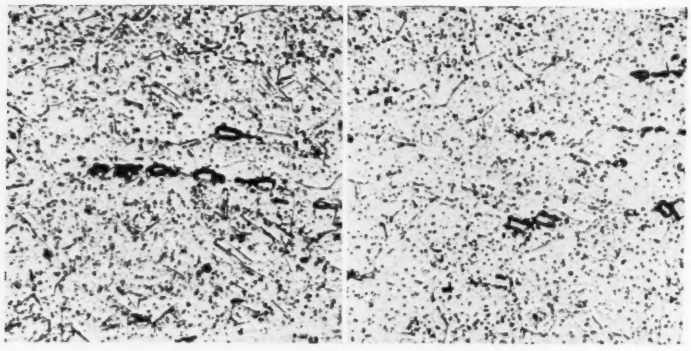

Fig. 9 Steel 4 (18/13/Nb) : (*a*) Rapidly heated to 1130° C. ; (*b*) heated for 5 min. at 1050° C. Etched in oxalic acid × 600

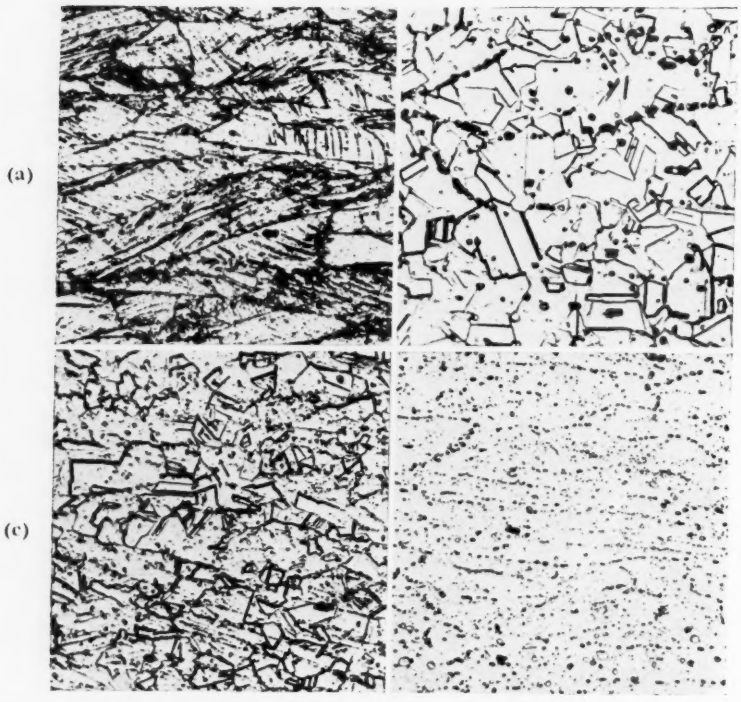

Fig. 10—Steel 5 (25/20) : (*a*) Heated for 5 min. at 850° C. ; (*b*) rapidly heated to 1130° C. ; (*c*) and (*d*) heated for 5 min. at 1050° C. (*a*), (*b*) and (*c*) etched in ferric chloride, (*d*) in oxalic acid × 400

Steels 4 (18/13/Nb) and 5 (25/20) in the cold-drawn condition do not show the rapid dark etching at slip planes and grain boundaries seen in the other steels. The cold-worked structure of the austenite can, however, be partly revealed by prolonged etching. This confirms that ferrite is not formed in these steels by cold-working, as shown by the magnetic tests.

The cold-worked structure of steel 4 after normal etching shows a regular distribution of fine carbide particles throughout the austenite matrix. Rapid heating below 1200° C. changes the amount or distribution of the carbide very little, and no precipitation is observed in the range 550–900° C. Above 1250° C. an appreciable amount of carbide goes into solution. The effects of heating for 5 min. are similar, but the carbides begin to dissolve noticeably at about 1150° C. Recrystallization of the austenite is first observed at 950–1000° C. in the rapidly heated specimens, and at 900–950° C. in those heated for 5 min. Rapid heating to 1130° C. gives a grain size about the same as 5 min. heating at 1050° C. (Figs. 9*a* and *b*).

The structure of steel 5 shows lines of carbide particles, which apparently mark the boundaries of some large previously existing austenite grains, together with some finer carbides regularly distributed. These carbides persist after rapid heating up to 1250° C. and after 5 min. heating up to 1150° C.; at higher temperatures they are partly dissolved. Rapid heating to between 550° and 900° C. causes the slip planes and grain boundaries to be darkened by ordinary times of etching, as seen in steels 1, 2, and 3. This is probably due mainly to carbide precipitation; the particles are, however, too small to be identified microscopically, so that some σ may also be present. The same structure is obtained after 5 min. heating (Fig. 10*a*). At higher temperatures this dark-etching effect disappears, and recrystallization of the austenite becomes apparent at 900–950° C. with both times of heating. The grain size of the specimen heated in a few seconds to 1130° C. (Fig. 10*b*) is about the same as that of one heated for 5 min. at 1050° C. (Fig. 10*c*). The carbide distribution (Fig. 10*d*) is the same in both cases.

Recommended Conditions for Rapid Softening

It is assumed that the cold-worked steel is to receive a final softening treatment, and that it is to be used in conditions requiring optimum corrosion resistance. The material should be fully softened, with an average grain size, and must be free from precipitated chromium-rich carbides, especially at the grain boundaries. Although the latter point refers especially to the unstabilized steels, carbide in any form should be kept to a minimum, so as to ensure optimum corrosion resistance. The ferrite content should also be kept as low as possible, since published information indicates that it can affect corrosion resistance under some conditions.[4] The σ phase should be absent, as it has an adverse effect on ductility and can lower the corrosion resistance.[2, 3] To meet these requirements with ordinary times of heating, steel manufacturers recommend softening at 1050° C., followed by rapid cooling.

The results of the present investigation show that rapid heating followed by immediate quenching does not lead to intercrystalline corrosion, so long as the temperature reached is high enough. The optimum treatment conditions are therefore determined by the need for obtaining satisfactory mechanical properties (indicated here by hardness and grain size), together with absence of σ and minimum ferrite and free carbides. The presence of some free carbide in the 18/13/1 and 25/20 steels is a permanent structural feature, and must be expected whatever softening treatment is applied.

The use of very short times of heating necessitates a slight increase in softening temperature, to ensure that precipitates are redissolved and to give about the same hardness and grain size as ordinary times of heating. It is therefore recommended that with a time of heating to temperature of 5–6 sec., followed by immediate quenching, the following softening temperatures should be employed:

Straight 18/8	1100–1150° C.
Ti-stabilized 18/8	1100–1150° C.
Mo-bearing 18/8	1100–1150° C.
Nb-stabilized 18/13	1125–1175° C.
25 Cr/20 Ni	1125–1175° C.

The optimum temperature ranges for other compositions are probably similar. It is important to ensure that material to be softened does not contain massive σ or carbide from incorrect treatment at an earlier stage of manufacture. Such massive constituents, once formed, are very difficult to take into solution, and would not be dissolved in a rapid-heating operation of a few seconds. Apart from such exceptional cases, the recommended treatment should give material with satisfactory characteristics.

Acknowledgments

The authors are indebted to Messrs. Tube Investments, Ltd., for permission to publish this paper, and to Dr. J. W. Jenkin for the interest he has taken in the work. They also wish to acknowledge the help given by several colleagues, particularly the late Mr. J. P. Reed, who designed the magnetic apparatus. The tubes used in the investigation were kindly made by the Talbot-Stead Tube Co., Ltd.

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Discussion on the Paper—

FULL-SCALE BLAST-FURNACE TRIALS*

By

J. A. Bond and T. Sanderson

(*The Discussion on this paper was published in the issue of the Journal for March, 1952. Mr. Sanderson's reply, printed below, was received too late for inclusion in that issue*).

Mr. **T. Sanderson** (Workington Iron and Steel Company) wrote in reply: Mr. Patchett asks how the coke rate at Workington was reduced from 19·44 cwt. to 16·88 cwt. He has virtually answered the question himself, as this was achieved by a combination of better ore preparation, better coke quality, and a reduction in slag volume; and he confirms our experience that much of the benefit of ore preparation can be lost by the use of inferior coke. The first step was to screen the ore at ½ in. and to sinter the fines. The burden then consisted of ore of a size 2½ in. to ½ in. and sinter. Coke quality was then improved from a shatter index of 78% of 1½ in. and 3·75% of −½ in. to 85% of 1½ in. and 2·75% of −½ in.

Mr. Towndrow asks for further information on the effect of the improved coke quality, and I would refer him to a paper by Sanderson and Wattleworth,† in which more details are given. All our statistical work shows that a reduction of 0·5% on the −½ in. shatter index would directly reduce the coke consumption by 0·5 cwt. per ton. The drop in performance of the furnaces when poor coke is encountered shows that the indirect effects are very marked.

I agree with Mr. Towndrow that care must be taken in interpreting data on breeze-blending experiments. Our further experiments did not add materially to our knowledge, owing to a mishap on one of the furnaces during the trial.

Both Mr. Towndrow and Mr. Baldwin have commented on the sinter experiment. A statistical analysis was not carried out, because of the limited number of weeks involved. We preferred to use correction factors which had been previously ascertained from a much greater amount of data.

There is no doubt that the slag volume has contributed to the improvement shown, but I cannot agree that the sinter percentage is only correlated with coke consumption at second hand. There is no significant correlation between sinter and slag volume for the period under review, nor indeed have we found it in any of our work. Generally, it would not be expected, because most of our sinter is made from the screenings below ½ in. from all ores. In fact, as the fines are generally poorer than the lumps, there would be, if anything, a tendency for sinter to be associated with more slag.

The point that Mr. Baldwin makes about the relationship between the slag volume and the burden constituents is, of course, important. Generally, the ores we use do not give more slag volume than is sufficient for good operation, and often we have to augment the slag volume deliberately. Our corrections, therefore, were associated only with the reducibility factor. They would not apply if ores that have more silica than is necessary to produce the optimum slag volume were used.

The order of the benefit of coke consumption which we were expecting was small. Our experience shows that 1% of sinter replacing 1% of fine ore reduces coke consumption by 0·04 cwt. per ton. In the trial recorded, sinter was replacing screened ore, and we were looking for an improvement of the order of 0·02 cwt. for each 1% increase in sinter. This was achieved, and Mr. Baldwin's statistical analysis agrees with it. One of our main reasons for carrying out the trial was to ascertain whether a large percentage of sinter could be carried in the burden. The experiment proved that this was so.

I thank Mr. Stirling for his suggestion, which I am following up.

In reply to Mr. Ledgard. I would say that the maximum of 84·4% of the Rice Rate was imposed solely by the limitation of blowing capacity. The furnace gave every indication of being able to take more wind had it been available.

* *J. Iron Steel Inst.*, 1951, vol. 168, pp. 24–39.

† T. Sanderson and D. R. Wattleworth, *J. Inst. Fuel*, 1950, vol. 23, pp. 115–120.

A PLANT FOR THE PICKLING, PHOSPHATING, AND PRIMING OF STEEL PLATES AND STRUCTURAL SHAPES

The Appleby-Frodingham Steel Company has recently installed a plant for pickling, phosphating, and priming plates and structural shapes, to meet a growing demand for steel in this condition.

The Footner Process has been adopted for the new plant, the complete cycle of operations being as follows:

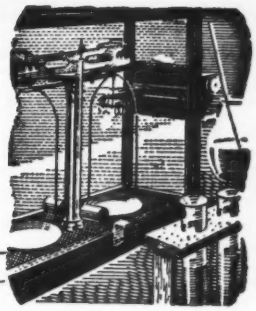
(i) Immersion in 5% sulphuric acid at 65° C. for 15–25 min.
(ii) After draining, two dips in water at 60–65° C.
(iii) Immersion for 3–5 min. in a solution containing 2% of free phosphoric acid and 0·3–0·5% of iron, at 85° C.
(iv) Priming while still warm.

The immersion in phosphoric acid produces an adherent coat of rust-inhibiting iron phosphate, which is an excellent key for paint. The steel is primed while still warm.

The plant is housed in a 160-ft. extension to the original stainless steel pickling plant. Three vats, each 40 ft. long by 5 ft. wide by 9½ ft. deep, contain the sulphuric and phosphoric acids and water, respectively. These vats are served by a 10-ton E.O.T. crane, which carries specially designed cradles and beams. Priming is carried out by brushing, which ensures a good bond between the phosphated surface and the paint. The maximum sizes which can be handled are of the order of 38 ft. long by 7 ft. wide for plates and 38 ft. long for sections.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Second Report of the Methods of Testing (Corrosion) Sub-Committee

SYNOPSIS

A series of tests has been carried out in a number of laboratories on the lines proposed in the First Report of the Sub-Committee. The results of outdoor tests have confirmed that the A.R.E. salt-droplet test gives a reasonable indication of the service performance of protective coatings. The reproducibility of the breakdown of protective schemes at scratches inflicted according to Provisional British Standard 1391 (1947) has proved adequate. Although satisfactory agreement has been found between the behaviour of coatings at the impact dome when subjected to both the A.R.E. test and outdoor exposure, observations made will not be of equal significance with those made at the scratches unless the severity of the blow is increased or the permissible spread of failure is reduced.

A new laboratory test, developed by the Chemical Research Laboratory, has given fair correlation with the results of outdoor exposure tests and is satisfactorily reproducible in different laboratories. Interim results, for five years' exposure, are presented for the original field test.

In an appendix, preliminary suggestions are made for the removal of corrosion products from mild-steel specimens carrying protective schemes of metallic coatings, with or without paint.

Introduction

THE First Report of the Methods of Testing (Corrosion) Sub-Committee was published in April, 1948.* Work has continued and the Sub-Committee consider it opportune to report on the further progress made.

The following were members of the Sub-Committee during the period under review :

Mr. W. E. BALLARD	Metallisation, Ltd.
Mr. C. BRAITHWAITE	Royal Aircraft Establishment
Mr. R. BUTCHER	The United Steel Companies, Ltd.
Dr. S. G. CLARKE	Armament Research Establishment
Mr. F. FANCUTT	Railway Executive, British Railways
Dr. J. C. HUDSON (*Chairman*)	British Iron and Steel Research Association
Mr. L. H. MCDERMOTT	Ministry of Works
Mr. R. St. J. PRESTON	D.S.I.R., Chemical Research Laboratory
Mr. G. E. RICHARDS	Post Office Research Station
Mr. R. E. SHAW	Imperial Chemical Industries, Ltd., Paints Division
Mr. W. E. WRIGHT	The Pyrene Co., Ltd.
Mr. E. E. WHITE (*Technical Secretary*)	British Iron and Steel Research Association.

Paper MG/BF/64/50 of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 10th April, 1952.

* *J. Iron Steel Inst.*, 1948, vol. 158, pp. 463–493.

The present report gives further details of two investigations referred to in the First Report, namely :

(*a*) The tests on industrial protective schemes embracing stoving paints, which have been concluded ; and

(*b*) The field test undertaken as part of the general investigation of laboratory performance tests.

The main feature is, however, an account of a collaborative investigation of the reproducibility of a new laboratory test and its suitability for specification purposes. This is the C.R.L. sulphur dioxide test, which, as the initials indicate, was developed at the Chemical Research Laboratory, Teddington.† It consists essentially in exposing specimens inside a covered beaker containing a dilute solution of sulphur dioxide. Condensation of moisture on the specimens is brought about by an electric heater, controlled by a thermostat, and a cooling coil.

The removal of corrosion products after test from specimens coated with composite protective schemes, such as a stoving paint over zinc-coated and phosphated steel, is often a difficult problem for which satisfactory methods have yet to be devised. Information regarding the Sub-Committee's experience on this point is given in the Appendix.

† R. St. J. Preston, *J. Iron Steel Inst.*, 1948, vol. 160, pp. 286–294.

INVESTIGATION OF THE REPRODUCIBILITY OF THE C.R.L. SULPHUR DIOXIDE TEST

Plan of the Investigation

The plan of the collaborative investigation is shown in Fig. 1. Its objects were, first, to ascertain how far the C.R.L. sulphur dioxide test was reproducible from one laboratory to another, and secondly, to check its suitability for testing protective coatings of different types.

In brief, standard sets of 12 specimens, each 6 in. × 2 in. × 20 S.W.G., were subjected to the C.R.L. test, an outdoor exposure test, and the A.R.E. salt droplet test.* Eleven laboratories collaborated in the work and most of them made all three tests.

Ten of the specimens were of mild steel of autobody quality ; one was an unprotected bright steel ' blank,' and the other nine carried different protective schemes, including phosphating and painting and metallic coatings of aluminium, lead, tin, and zinc, both bare and stove-painted. The remaining two specimens were of sprayed aluminium on aluminium, and sprayed zinc on zinc.

The specimens of electrodeposited tin *I* were prepared for painting by immersion for 1 min. in an aqueous solution at 80° C. (176° F.) containing 2% of caustic soda, 0·9% of trisodium phosphate, and 0·8% of sodium dichromate, plus a small amount of wetting agent, after which they were rinsed in hot water and dried.†

The electrodeposited zinc specimens *K* were phosphated before being painted. The process differed from that used for the phosphated steel specimens *B*. Both processes were proprietary and of the short-period immersion type, 6 min. at 185° F. for *B* and 2 min. at 165° F. for *K*. Immersion in the phosphating baths was followed by successive rinsings in hot water and in hot dilute chromic-acid solution, and drying in an oven.

All the coating operations were carried out under controlled conditions and a satisfactory degree of uniformity was achieved, as is shown by the figures for the coating thicknesses given in Table I. These were calculated from the coating weights, as determined by weighing the specimens before and after each stage in their preparation.

The paint used, which complied with specification C.S.2249, is an off-white priming paint for dipping and stoving application, based on an oleo-resinous vehicle, with lithopone and titanium dioxide pigments. It was applied by dipping and the specimens

* Details of this test are given in Provisional B.S. 1391 (1947). In the Sub-Committee's First Report this test is called the A.R.D. test ; the change in designation is due to the change of name to the Armament Research Establishment.

† This treatment would not now be used for tin coatings that are to be painted, unless a period of storage under adverse conditions was expected to elapse between plating and painting ; moreover, a minimum temperature of 85° C. would be specified for the dipping solution.

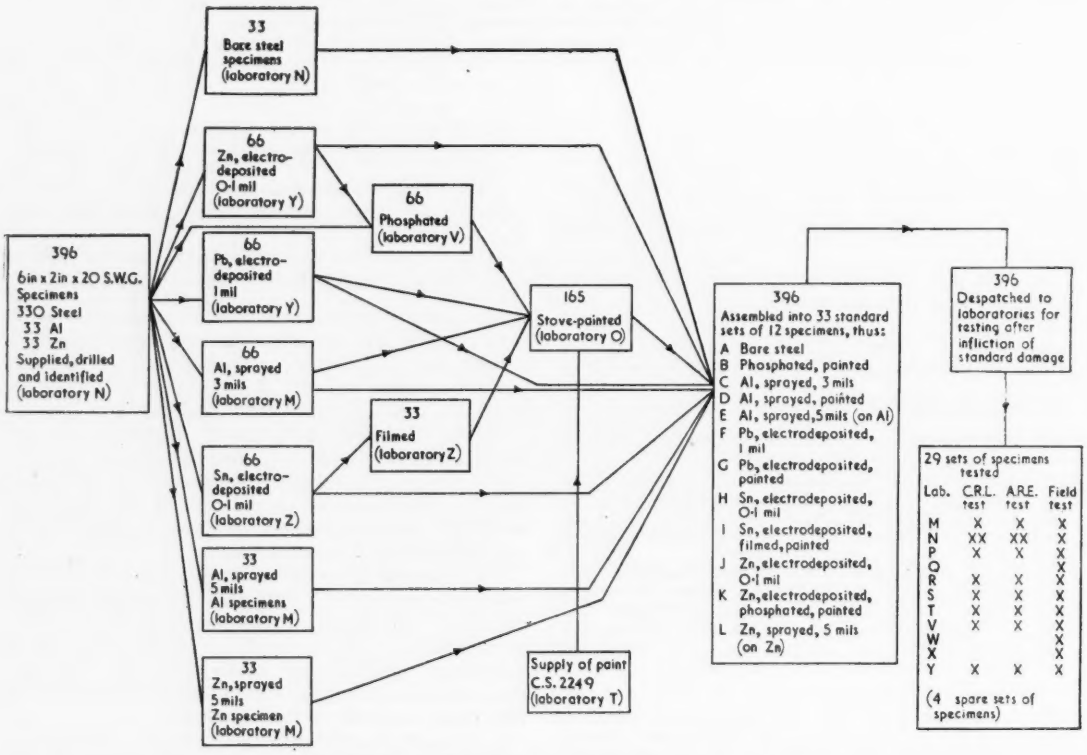


Fig. 1—Schedule of collaborative investigation of the C.R.L. test

were stoved for 20 min. at 350° F. after draining for about 20 min.

Conduct of the Tests

Damage to Protective Coatings—Before the specimens were exposed to tests all the protective coatings were damaged by scratching and indentation as specified in Provisional B.S. 1391 (1947), except that the positions of the damage were altered to suit the smaller size of specimen* (*see* Fig. 2).

C.R.L. Sulphur Dioxide Test—The apparatus used for the C.R.L. test (Fig. 3) consists of a 5-l. beaker fitted with a lid from which twelve 6-in. × 2-in. × 20 S.W.G. specimens are suspended radially inside it. The beaker is placed on an electric heater controlled by a thermostat inserted through a central tube. A lead coil is wrapped round the lower part of the beaker and cold water is circulated through it to promote internal condensation of moisture.

The procedure adopted in the Sub-Committee's tests was the same for all laboratories but differed slightly from that subsequently standardized.† The tests were started on a Monday morning by pouring 500 ml. of distilled water at 65° C. into the beaker. The specimens were placed on the suspension hooks, leaving their lower edges about 1½ in. above the water. Five ml. of SO_2 solution (0·32 g. of SO_2/100 ml. of H_2O) were added to the beaker at the beginning and end of each full working day and the entire solution was replaced each Monday morning by distilled water.

The thermostat was placed about 1½ in. above the solution and was set to 45° C.; the corresponding temperature of the solution was 65° C. Both temperatures were checked daily by glass thermometers, which were withdrawn and replaced by bungs after the readings had been taken. The thermostat, cooling coil, and heater ran continuously over the whole test, which lasted for 28 days.

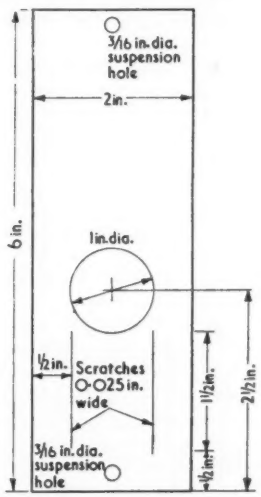


Fig. 2—Method of damaging the specimens with anvil used in indentation machine. Energy of blow 18 in.-lb.

* 6-in. × 4-in. specimens are specified in Provisional B.S. 1391 (1947).

† The standard procedure is given in the revised edition of Provisional B.S. 1391 (1947), now in the press.

Table I

AVERAGE THICKNESS OF PROTECTIVE COATINGS TESTED

Coating	Used for Protective Schemes Reference	Average Thickness, mils	Probable Error*
Phosphate			
On steel	B	0·05†	...
On electrodeposited zinc	K	0·05†	...
Al, sprayed			
On steel	C and D	2·9	0·037
On Al	E	5·1†	...
Pb, electrodeposited	F and G	1·04	0·004
Sn, electrodeposited	H and I	0·102	0·00065
Zn, electrodeposited	J and K	0·115	0·0007
Zn, sprayed			
On Zn	L	4·5†	...
Stoving paint C.S.2249	B, D, G, I and K	0·87	0·0053

* Calculated as $\frac{5}{6}\sqrt{\Sigma d^2/n(n-1)}$, where d is the deviation of each of the n individual results from the average

† Determined on 3 extra specimens only. All other results refer to all the specimens prepared, of which there were 33 in each reference set

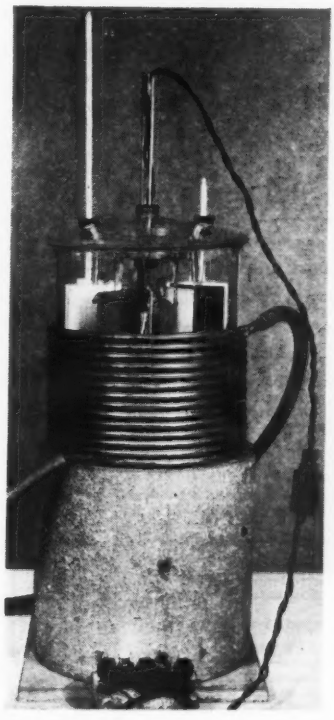


Fig. 3—Apparatus for the C.R.L. test

To reduce any positional effect within the beaker, the assembly of specimens was moved clockwise through 90° each time fresh sulphur dioxide solution was added, and each specimen was turned upside-down or front-to-back once in each working day.

Outdoor Exposure Test—Each set of 12 specimens was secured in a single row to two thin battens at their tops and bottoms by rust-resisting steel screws ; plastic washers were used to lift the specimens clear of the wood and to insulate them from the screws. The assembled sets were sent out in this form and were exposed outdoors at an angle of 45° by the collaborating members.

A.R.E. Salt Droplet Test—The A.R.E. test was carried out in accordance with Provisional B.S. 1391 (1947) for a period of 28 days. It was found unnecessary to spray the painted specimens every day because the droplets of spray retained their shape, but daily spraying was necessary for specimens with unpainted metallic coatings, on which the droplets were less permanent.

Assessment of Failure

In both laboratory tests the specimens were inspected on each working day. Outdoor inspections were made weekly over the first month and monthly for the next five months. Thereafter, the inspection interval has been three months.

Systematic records were made for all tests of the percentage of rusting, blistering, and flaking on the upper undamaged halves of the front and back of each specimen, ignoring a band $\frac{3}{8}$ in. wide round the edges. The spread of rusting, blistering, or flaking from the damaged areas (indentation and scratches) and from the edges was also measured.

A protective scheme was judged to have failed when it ceased to satisfy the following criteria laid down in Provisional B.S. 1391 (1947) :

(a) *General*—There shall be no flaking, blistering or other defect of the protective coating, and not more than 0·5% (by area) of rust and rust stain on the upper undamaged half of the front or back surface of the specimen.

(b) *On or at the scratches*—

(i) There shall be no rust or rust stain extending at any point beyond $\frac{1}{16}$ in. from the original boundaries of the scratches.

(ii) Except as in (i) there shall be no flaking, blistering, lifting, or other defect of the protective coating extending beyond $\frac{1}{32}$ in. from the original boundaries of the scratches.

(iii) In making these assessments the portions of the scratches lying within $\frac{3}{8}$ in. of the bottom edge shall be ignored.

(c) *On the front (protruding) surface of the impact dome*—Rust or rust stain and any flaking, blistering, or other defect of the protective coating shall not extend beyond $\frac{1}{4}$ in. from the centre of the dome. So as to avoid any error due to drainage of rust-bearing solution downwards from the dome, the measurements shall be confined to the upper part of the dome.*

* This last sentence cannot be rigidly applied to the C.R.L. test, in which the specimens are turned upside-down.

Table II

LIVES TO FAILURE OF THE PROTECTIVE SCHEMES IN THE LABORATORY TESTS, DAYS*

	Protective Schemes	Laboratory															
		C.R.L. Test								A.R.E. Test							
		M	N[1]	N[2]	P	R	S	T	V	M†	N[1]	N[2]	P	R	S	T	V
A	None: bare steel	1	1	1	1	1	1	1	1	F	1	1	1	1	1	1	1
B	Phosphated, painted	21sb	8sb	11sb	28sr	1sr	8sb	18	2dr	F	8dr	11	7dr	3sdr	14	7dr	2dr
C	Al, sprayed, 3 mils	—	—	—	—	8	7	28	—	—	—	—	—	—	—	18	—
D	Al, sprayed, 3 mils, painted	14	—	—	10dr	8dr	7dr	—	—	—	—	—	—	—	8sr	23sdr	—	28
E	Al, sprayed, 5 mils, over Al	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F	Pb, electrodeposited, 1 mil	25	18	23	4	1	7	1	—	F	2	3	2	1	4	1	3
G	Pb, electrodeposited, 1 mil, painted	—	—	—	—	—	—	—	—	—	23sr	—	10sr	12sr	15sr	3sr	4sr
H	Sn, electrodeposited, 0·1 mil	1	3	3	1	1	1	3	2	F	2	2	1	2	5	2	1
I	Sn, electrodeposited, 0·1 mil, filmed, painted	28sb	14sb	14sb	24sr	2sbr	14sb	24sb	14sb	—	—	—	28sr	5sr	—	28	22
J	Zn, electrodeposited, 0·1 mil	3	7	2	3	1	2	1	1	—	—	—	—	—	—	—	—
K	Zn, electrodeposited, 0·1 mil, phosphated, painted	—	9sb	—	—	—	—	28sr	—	—	—	—	—	15sb	—	—	—
L	Zn, sprayed, 5 mils, over Zn	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* A dash indicates that the protective scheme had not failed after 28 days. The cause of failure was general rusting on the undamaged surface, except where indicated thus:
d = failed at dome s = failed at scratch
b = failed by blistering r = failed by rusting

† No intermediate inspections were made at this laboratory. Specimens that had failed when the test was concluded after 28 days are shown thus : F

Results

Laboratory Tests—Tests by both the A.R.E. and the C.R.L. methods were made in each of seven laboratories, one of which also made a repeat test. The observed lives to failure of the protective schemes and their orders of merit are given in Tables II and III.

Correlation coefficients for each type of test have been calculated by the Spearman ranking method between all the orders of merit shown in Table III, taken in pairs. For the C.R.L. test, the average value of the correlation coefficient is 0·79, the best correlation 0·99 being between laboratories *R* and *S*. The corresponding figures for the A.R.E. test are: best correlation 0·97 (between laboratories *P* and *N*[2]), average value 0·89. From these figures it might be concluded that the C.R.L. test was rather less reproducible than the A.R.E. test, but this is doubtful because the C.R.L. test had not previously been used outside the Chemical Research Laboratory, and better reproducibility would, no doubt, be achieved with further experience. The chief irregularity in the results of the C.R.L. test is the erratic behaviour of protective scheme *C* (sprayed aluminium, 3 mils) in the different laboratories. These specimens all rusted badly at the top edge, and in some cases the rust spread downwards over their surfaces, causing failure to be reported at an early stage.

The correlation between the results of the tests made by the two methods in the same laboratory was not good. The best correlation coefficient between the two orders of merit was 0·52 (laboratory *P*) and the worst 0·08 (laboratory *R*). The average orders of merit in the two types of test deduced from the results obtained in all the laboratories (*see* Table IV) show a low correlation of only 0·28. The main causes of this low correlation are that protective scheme *G* (lead electrodeposited, 1 mil painted) has performed better and protective scheme *J* (zinc electrodeposited, 0·1 mil) worse in the C.R.L. test than in the A.R.E. test. This is in line with practical experience in industrial atmospheres polluted with sulphur compounds, where lead coatings show good resistance, but thin unpainted zinc coatings fail rapidly. It was noteworthy that in the A.R.E. test and in the field test early rusting occurred on the unpainted lead-coated specimens (*F*) at discontinuities in the electrodeposit; failure at these points was not observed in the C.R.L. test. The effect of these discrepancies on the correlation coefficient is shown by the fact that if protective schemes *G* and *J* are omitted from the calculation, the coefficient becomes 0·96.

Table IV

AVERAGE ORDERS OF MERIT IN THE LABORATORY TESTS

Protective Scheme	C.R.L. Test	A.R.E. Test
B	6	7
C	4	3
D	3	4
F	7	8
G	2	6
H	8	9
I	5	5
J	9	1
K	1	2

As a further check of the reproducibility of the tests from one laboratory to another, the changes in weight of the specimens after the 28 days' testing were determined (*see* Table V). The results represent the difference between the final weight of the specimens (after drying at 100° C. for 1 hr.) and their initial weight in the fully coated condition.

The correlation coefficient between the orders of merit of the specimens based on the average gains in weight in the two tests is 0·86. The following correlation coefficients have also been calculated for the nine specimens other than the control specimens *A*, *E*, and *L*, using average figures for all the laboratories:

Life to failure in C.R.L. test/life to failure in A.R.E. test 0·28

Gain in weight in C.R.L. test/gain in weight in A.R.E. test 0·77

The low value of the first coefficient is associated, as explained, with the differences in the behaviour of protective schemes *G* (lead electrodeposited, 1 mil, painted) and *J* (zinc electrodeposited, 0·1 mil) in each test.

The losses in weight of the bare steel control specimens after they had been de-rusted are given in Table VI. The individual figures show considerable scatter, which is of the same order of magnitude as the scatter for the corresponding gains in weight (*see*

Table III

ORDERS OF MERIT OF THE PROTECTIVE SCHEMES IN THE LABORATORY TESTS

Protective Scheme	C.R.L. Test								A.R.E. Test							
	Laboratory								Laboratory							
	M	N[1]	N[2]	P	R	S	T	V	M	N[1]	N[2]	P	R	S	T	V
B	5	6	7	6	5	5	6	7	8	7	7	7	8	7	7	7
C	3	3	4	1	7	7	5	2	2½	4	4	4	1½	1	6	2
D	6	2	2	4	3	3	1	4	2½	3	2½	3	4	4	3	4
F	7	7	5	7	6	6	7	5	7	9	9	8	7	9	8	8
G	2	1	3	3	1½	2	2	3	5	6	5	6	5	6	5	6
H	9	8	8	9	8½	9	8	8	9	8	8	9	9	8	9	9
I	4	4	6	5	4	4	4	6	6	5	6	5	6	5	4	5
J	8	9	9	8	8½	8	9	9	2½	1	2½	2	1½	2	1½	1
K	1	5	1	2	1½	1	3	1	2½	2	1	1	3	3	1½	3

Table V

GAIN IN WEIGHT OF SPECIMENS AFTER 28 DAYS' LABORATORY TESTING, CENTIGRAMMES

Specimen Reference	Laboratory								Average	Order of Merit
	M	N^1	N^2	P	R	S	T	V		
C.R.L. Test										
A	91	99	120	110	109	73	68	112	98	12
B	1	1	1	1	1	1	−1	1	1	3
C	31	39	42	39	38	40	30	42	38	9
D	1	3	2	2	1	1	4	2	2	5
E	51	49	53	46	37	36	42	53	46	10
F	14	16	15	16	10	10	14	6	9	6
G	3	Nil	1	2	1	1	Nil	Nil	1	4
H	11	19	21	13	24	12	8	22	16	7
I	−1	−1	Nil	Nil	−1	−1	−2	Nil	−1	2
J	86	93	103	118	106	61	72	102	93	11
K	−1	−1	−1	Nil	−2	−1	−2	−1	−1	1
L	33	34	31	31	37	28	41	39	34	8
A.R.E. Test										
A	249	209	144	204	274	149	192	288	214	12
B	1	3	1	2	3	10	2	5	3	4
C	30	27	32	36	41	32	39	31	34	10½
D	5	5	5	3	11	10	13	11	8	6
E	29	32	29	32	33	32	42	39	34	10½
F	8	26	10	20	46	18	28	38	28	8
G	Nil	1	1	1	2	4	1	2	2	1
H	2	4	3	7	8	4	4	8	5	5
I	Nil	2	3	1	1	11	Nil	1	2	2
J	19	16	15	19	19	25	17	30	20	7
K	Nil	3	1	1	3	12	Nil	Nil	3	3
L	31	24	21	27	30	43	43	37	32	9

Table V). In two laboratories (N^2 and S) the loss in weight of the 6-in. × 2-in. steel control blanks in the A.R.E. test fell below half the figure, 4·1 g. after 28 days' test, specified in Provisional B.S. 1391 (1947), for a specimen double the size (6 in. × 4 in.). The probable explanation is that the specimens had not been sprayed heavily enough.

Variations in temperature from one laboratory to another will affect the losses in weight of the blanks. The A.R.E. test is made at room temperature and limits of 55–70° F. are specified in Provisional B.S. 1391 (1947). In the C.R.L. test temperature is controlled by thermostats stated to be accurate to ± 3° C.; the degree of control achieved is shown by the following average vapour temperatures recorded in the various laboratories:

Laboratory	Vapour Temperature, °C.	Laboratory	Vapour Temperature, °C.
M	44·0	*R*	47·0
N^1	47·2	*S*	42·5
N^2	46·7	*T*	47·0
P	44·5	*V*	48·0

Average Vapour Temperature, °C.

45·9

Observations made on typical sets of specimens throughout the tests in laboratory *N* are summarized in Table VII, and the final condition of the two sets of C.R.L. test specimens when the tests were completed after 28 days is shown in Fig. 4.

Field Tests—Sets of specimens have been exposed outdoors at 11 different places. After one year's exposure, all the protective schemes applied to steel specimens had failed (*see* Table VIII), with the exception of schemes *C* and *D* (aluminium sprayed, 3 mils unpainted and painted) and *G* (lead electrodeposited, 1 mil, painted).

Orders of merit of the nine protective schemes applied to steel are given in Table IX for each exposure site and for periods of 3, 6, and 9 months. For some protective schemes the position in the orders of merit changes with increasing duration of exposure; for others the ranking after a given exposure period differs from one station to another. The effect of duration of exposure is most marked for the sprayed aluminium coatings (*C* and *D*) and the electrodeposited zinc coatings (*J* and *K*), both bare and painted; the

Table VI

LOSS IN WEIGHT OF BARE STEEL CONTROL SPECIMENS IN THE LABORATORY TESTS, GRAMMES

Laboratory	C.R.L. Test	A.R.E. Test
M	2·67	3·50
N^1	2·76	3·26
N^2	3·46	1·94
P	4·94	3·70
R	3·09	4·00
S	2·36	1·51
T	4·61	3·32
V	3·31	4·65
Average, x	3·40	3·24
Probable error,* d	0·22	0·25
Ratio d/x, %	6·5	7·6

* Calculated as in Table I

Table VII

OBSERVATIONS MADE DURING TESTS IN LABORATORY *N*

Protective Scheme	C.R.L. Test	A.R.E. Test
A	Covered with rust during whole of test	Rust-spotted for first week and then covered with rust
B	Breakdown at damage began at once. At end of test, failed at scratch by blistering and rust; dome heavily rusted; edges badly rusted and blistered, but surface intact	Rust developed at damage within a few days. At end of test, scratch failed from rust and blisters and dome by spread of rust; rust spotting from edges spreading inwards to surface
C	Covered with black stain for first week, then cleared. Top edge rusted heavily after 1 week. Slight rusting at damage	Covered with black spots which persisted throughout the test. White CP* visible on these spots towards the end
D	Slight rusting at damage	No change
E	Covered with black spots for first week, then cleared. White CP* at edges	Similar to scheme C
F	Covered with white CP after one day. Rust spread from edges towards end of test	Surface covered with patches of rust at end of week. Gradually became worse
G	Slight rusting at damage. White CP where lead exposed at damage. Surface intact	Heavy rusting at damage, especially scratch. Surface intact
H	100% rust stain after one day. At end of test completely rusted	100% rust stain after one day. At end of test about half rusted
I	Rusting at damage at once. Blistering at scratch after one week. At end of test scratch failed and dome fairly heavily rusted; edges rusted; surface intact	Slight rusting at damage after one week. Rusting at edges. Surface intact
J	Covered with white CP after one day. Rust spreading from edges after 3 days. 100% rust after 9 days	Surface mottled and covered with white CP
K	Rusting at damage after about 2 weeks. Slight blistering at scratch. Surface intact	No change
L	Covered with white CP after one day	Similar to scheme J

* CP = Corrosion product

aluminium coatings have improved their position with increasing time, but the zinc coatings have fallen in the order of merit. These observations demonstrate that there can be no single fixed order of merit for a number of different protective schemes; the order varies with the conditions and duration of exposure. This fact has to be taken into consideration when correlating the results of laboratory tests with those of service.

The correlations between the average orders of merit of the protective schemes in the field tests after 3, 6, and 12 months' exposure and the order of merit observed in the two laboratory tests are given in Table X. Both tests gave fairly good correlation with the field tests up to 6 months' exposure. Thereafter, the correlation between the field test and the A.R.E. test became worse, but that between the C.R.L. test and the field test improved, mainly because the thin electrodeposited zinc coatings (*J* and *K*) had not failed by rusting within the duration, 28 days, of the A.R.E. test. In the field tests these coatings failed from three months onwards, according to the severity of the atmosphere.

Orders of merit of the protective scheme for each exposure station have also been computed from the lives to failure (*see* Table XI). The correlation coefficients between the average order of merit on this criterion and the orders of merit in the laboratory

Table VIII

LIVES TO FAILURE OF THE PROTECTIVE SCHEMES IN THE FIELD TEST, YEARS*

Laboratory	Where Exposed	Corrosion Rate,† mils/yr.	Protective Scheme								
			B	C	D	F	G	H	I	J	K
M	Dudley	3·8	0·04	—	—	0·08	0·73sb	0·02	1·00	0·38	0·73
N	Birmingham	3·9	0·17	—	—	0·25	—	0·02	0·98	0·74	0·74
P	Derby	5·0	0·08dr	—	—	0·15	—	0·15	—	0·23	0·75
Q	Dollis Hill	3·7	0·08	1·00	0·04	0·02	0·06	0·02	0·04	0·23	0·31
R	Teddington	2·8	0·08	—	—	0·04	1·00	0·02	1·00	0·52	1·00
S	Stocksbridge	3·9	0·08	—	—	0·08	—	0·08	—	0·23	1·00
T	Slough	3·3	0·50	—	—	0·04	—	0·04	—	0·99	—
V	Brentford	4·0	0·15	—	—	0·06	—	0·06	0·15	0·32	0·98
W	Farnborough	2·1	0·33	—	—	0·04	—	0·04	0·84	1·00sr	—
X	Barnet	2·6	0·54	—	—	0·08	—	0·08	1·06	1·06	1·06
Y	Woolwich	3·0	0·04	—	—	0·04	0·75sb	0·04	1·00	0·51	—

* A dash indicates that the protective scheme had not failed after 1 year's exposure. The cause of failure was rusting on the undamaged surface except where indicated thus:
d = failed at dome s = failed at scratch
b = failed by blistering r = failed by rusting

† Deduced from the losses in wt. of bare steel control specimens exposed for 1 year. These specimens have been replaced by similar new specimens

Table IX

ESTIMATED ORDERS OF MERIT OF THE PROTECTIVE SCHEMES IN THE FIELD TESTS

Protective Scheme	Laboratory											
	M	N	P	Q	R	S	T	V	W	X	Y	Av.
3 Months' Exposure												
B	8	8	7	6	7	8	7	7	7	5	7	7
C	2½	4	3	1	4	1	1	4	6	7	3	3
D	5	2	2	3	3	2½	5	3	3	5	6	4
F	7	7	8	8	8	7	8	8	8	8	8	8
G	2½	5	5	7	7	2½	3	5	1½	2	4	5
H	9	9	9	9	9	9	9	9	9	9	9	9
I	6	6	4	5	6	6	6	6	4	5	5	6
J	2½	2	6	4	2	5	3	1½	5	2	2	2
K	2½	2	1	2	1	4	3	1½	1½	2	1	1
6 Months' Exposure												
B	7	7	6	6	6	7	7	6	7	7	6	7
C	1½	2	1½	1	5	1½	2	2	6	6	1	1
D	1½	2	1½	5	1½	1½	5	1	5	1	5	2
F	8	8	8	8	8	6	8	7	8	8	8	8
G	3	6	4	2	3	4	4	3	2½	3	4	3
H	9	9	8	8	9	8	9	9	9	9	9	9
I	5	5	3	4	1½	3	6	5	2½	4	3	5
J	6	2	8	8	7	9	2	8	4	2	7	6
K	4	4	5	3	4	5	2	4	1	5	2	4
12 Months' Exposure												
B	7	7	6	6	6	8	7	6	7	6	7	6
C	1½	1½	2	2	2	2	4	2	4	3	1	2
D	1½	1½	1	4	1	2	1½	1	3	1	2	1
F	6	6	7	8	8	6	8	8	8	8	6	7
G	3	3	4	1	3	4	1½	3	1	2	4	3
H	9	9	8	8	9	7	9	8	9	9	9	9
I	4	4	3	3	4½	2	5	5	6	5	5	5
J	8	8	9	8	7	9	6	8	5	7	8	8
K	5	5	5	5	4½	5	3	4	2	4	3	4

tests (*see* Table IV) are 0·73 for the C.R.L. test and 0·62 for the A.R.E. test. Both figures are reasonably satisfactory.

There is a fairly good correlation (0·74) between the lives to failure in the field tests of the thin electrodeposited zinc coating (*J*) and the rates of rusting of the bare steel control specimen at the different stations. Otherwise the lives of the protective schemes at the various stations bear little relation to the corresponding rates of rusting of mild steel.

The condition of the specimens after one year's exposure at Birmingham (laboratory *N*) is described in Table XII, and the appearance of the specimens exposed at Slough (laboratory *T*) for the same period is shown in Fig. 5.

Conclusions

The results of these experiments show that the C.R.L. test should prove a useful addition to laboratory tests for corrosion resistance. It is simple to carry out, and may be less affected by the personal factor than the A.R.E. test.

The correlation between the results of these two laboratory tests is only moderate, but this is explicable to some extent by the nature of the protective schemes tested. The tests are best regarded as complementary and each will, no doubt, prove to have its particular field of usefulness. It may be found that the C.R.L. test simulates attack by an industrial atmosphere better than the A.R.E. test, but that the latter is more representative of mildly corrosive conditions.

The A.R.E. test does not corrode metallic coatings so rapidly as the C.R.L. test but it serves to reveal defective or uncoated areas in some types of coating, such as lead or tin. Some thick metallic coatings prevent rusting for 28 days in either test and it will prove difficult to devise a laboratory test that will cause breakdown of metallic coatings of appreciable thickness within a reasonable time. Probably the best available procedure for assessing such coatings is to determine their thickness and to check their porosity and adhesion.

FINAL RESULTS OF TESTS ON INDUSTRIAL PROTECTIVE SCHEMES EMBRACING STOVING PAINTS

Introduction

The main object of the research described in this

Table X

CORRELATION BETWEEN THE RESULTS OF FIELD TESTS AND OF LABORATORY TESTS

Duration of Exposure in the Field Tests, months	Correlation Coefficient	
	C.R.L. Test	A.R.E. Test
3	0·47	0·97
6	0·73	0·62
12	0·83	0·38

Table XI

ORDERS OF MERIT OF THE PROTECTIVE SCHEMES IN THE FIELD TESTS BASED ON LIVES TO FAILURE

Protective Scheme	Laboratory											
	M	N	P	Q	R	S	T	V	W	X	Y	Av.
B	8	8	9	4	7	8	7	6½	7	7	8	7
C	1½	2	2½	1	1½	2½	3	2	2½	2	2	1
D	1½	2	2½	6½	1½	2½	3	2	2½	2	2	2
F	7	7	7½	8½	8	8	8½	8½	8½	8½	8	8
G	4½	2	2½	5	4	2½	3	2	2½	2	5	3
H	9	9	7½	8½	9	8	8½	8½	8½	8½	8	9
I	3	4	2½	6½	4	2½	3	6½	6	5	4	5
J	6	5½	6	3	6	6	6	5	5	5	6	6
K	4½	5½	5	2	4	5	3	4	2½	5	2	4

section was to determine the correlation between the performance of representative protective schemes in the A.R.E. test and their behaviour when exposed outdoors. For this purpose nine sets of mild-steel specimens, 6 in. × 4 in. × 20 S.W.G., were prepared under industrial conditions.* Each set included specimens that had been treated by each of the following methods:

(i) No surface treatment other than degreasing; primed with a single coat of stoving paint
(ii) Phosphated; primed with a single coat of stoving paint
(iii) Phosphated; primed and finished, *i.e.*, with two coats of paint
(iv) Coated with electrodeposited zinc (0·4 mil): phosphated; primed with a single coat of stoving paint.

There were about 30 specimens in each set, and the phosphating and painting treatments were those in operation at each particular works.

Sets of specimens were subjected to the A.R.E. test in several laboratories, and a single set was exposed outdoors at Birmingham. All the sets were inspected periodically and the failure of the protective schemes was assessed as specified in Provisional B.S. 1391 (1947).

Subsidiary tests were also made to ascertain how far the degree of failure of the protective schemes at the impact dome was affected by the energy of the blow used to inflict the damage.

The first results of the laboratory tests on both the main and the subsidiary series of specimens were given in the Sub-Committee's First Report. As, however, many of the protective schemes had not failed at that time in the outdoor test, the correlation of the two series of results was necessarily provisional. The outdoor test has now been completed and a final correlation will be made in the present report. Attention will also be paid to the reproducibility of the performance of the protective coatings at the standard scratches, and to the extent to which behaviour at the impact dome is a determining factor in the tests.

* First Report: *loc. cit.*, pp. 481–490.

Table XII

APPEARANCE OF THE SPECIMENS AFTER ONE YEAR'S EXPOSURE AT BIRMINGHAM

Protective Scheme	Front	Back
A	100% rust	100% rust
B	100% rust stain, 50% rust in spots	100% rust stain, 20% rust in spots
C	Intact: slight rust stain at edges	Intact
D	Intact: paint 80% flaked off	Intact
E	Intact	Intact
F	10% rust and 50% rust stain in streaks	50% rust and rust stain in streaks
G	Surface intact: blistering at scratch	Intact
H	100% rust	100% rust
I	1% rust and rust stain spreading from top edge: blistering at scratch	0·2% rust and rust stain
J	100% rust	10% rust spreading in from edges
K	2% rust and rust stain spreading from top edge	Intact
L	White corrosion product at edges	White corrosion product at edges

Correlation of the Results of the Field Test with the Results of the A.R.E. Test

The specimens exposed at Birmingham were removed in July, 1949, after three years' exposure. The durations of test to failure of the protective schemes are stated in Table XIII.* After the test the specimens were washed in warm soapy water, dried and weighed, but, as the changes in weight bore no relation to the observed life of the protective scheme, they are not given here.

The corrosiveness of the atmosphere at the exposure site may be judged from the rate of attack on bare steel control specimens. This was 3–4 mils/year, as compared with rates of from 5 mils/year upwards in industrial atmospheres.

The most interesting feature of the results lies in their comparison with those of the A.R.E. test on the same protective schemes (*see* Table XIII). If the average durations to failure for each protective scheme in the two tests are compared by Spearman's

* Some of the figures given in Table XX of the First Report have been revised because in previous assessments blistering and flaking of the paint were disregarded. These factors have now been taken into consideration. The change has had a marked effect on the figures for the zinc-coated, phosphated, and primed specimens.

Table XIII

RESULTS OF OUTDOOR EXPOSURE AND A.R.E. TESTS AT BIRMINGHAM

Specimens from Firm No.	Duration of Test to Failure, days, and Cause of Failure*											
	Phosphated and Primed				Phosphated, Primed, and Finished				Electrodeposited Zn, Phosphated, and Primed			
	1	2	3	Av.	1	2	3	Av.	1	2	3	Av.
Outdoor Exposure Test												
1	77r	56r	98rs	77	77s	325s	144s	182	271r	271r	165r	236
2	77r	77r	98rs	84	98s	165s	182s	148	119r	144r	28r	97
3	98rs	98rs	77r	91	144r	271r	271rs	229	119r	119r	119r	119
4	77r	56r	98r	77	98s	77s	165s	113	144r	119r	119r	127
5	98r	119r	144rs	120	325s	182s	144s	217	271rs	182r	144r	199
6	35s	21s	28s	28	35s	56s	35s	42	119r	144r	144r	136
7	35r	144r	35rs	71	144s	119s	325s	196	565r	325s	461r	450
8	98s	144r	98s	113	565r	271s	565s	467	144r	98r	98r	113
9	77r	77rs	56s	70	325rs	98s	165s	196	119r	119r	144r	127
Average				81				199				178
A.R.E. Test												
1	13r	20rs	12rs	15	83s	47s	69r	66	9rs	10r	12r	10
2	8s	9r	14r	10	36s	50s	28r	38	14rs	10r	14rs	13
3	6r	5s	5s	5	23s	29s	6s	19	2s	3rs	3r	3
4	3s	2s	2s	2	9s	12s	9s	10	>29	>29	>29	>29
5	7s	22rs	17rs	15	34s	27s	22s	28	20r	20r	17r	19
6	5r	6r	7r	6	9s	9s	9s	9	>29	>29	>29	>29
7	3r	8rs	5rs	5	12s	7s	10r	10	22r	>29	22r	>24
8	6r	5rs	9rs	7	104s	104s	104s	104	27r	27r	>29	>28
9	3r	6rs	2s	4	10s	10s	10s	10	7s	10r	12rs	10
Average				7·8				32·7				>18·3

* r = failed through rusting on undamaged area
s = failed at the scratches

ranking method, a correlation coefficient of 0·64 is obtained. It was difficult, because of blistering, to assess the results of the A.R.E. test on electrodeposited zinc, phosphated, and primed specimens; if this group of specimens is omitted, the correlation coefficient rises to 0·74. Although this value is slightly less than that of 0·81 given in the First Report after one year's outdoor exposure, it is sufficiently high to show that the A.R.E. test gives a fair indication of the relative performance of protective schemes of the type tested when exposed outdoors.

Reproducibility of Breakdown at the Scratches

Three specimens of each protective scheme were tested and two standard scratches were inflicted by hand on each specimen before exposure, so that for each protective scheme comparisons are possible for its behaviour at six supposedly identical scratches. It was thought of interest, as bearing on the general technique of laboratory testing, to make a statistical study of the reproducibility of the results obtained at the scratches in the field test. The results for electrodeposited zinc, phosphated, and primed specimens, have, however, been omitted from this analysis, because few of them failed at the scratches; presumably the scratches were protected cathodically by the zinc coating.

Values of the observed duration to failure at each scratch are given in Table XIV, with averages and probable errors. On the whole the values of the probable error are satisfactorily low. It is concluded, therefore, that the scratches are sufficiently reproducible. This conclusion was confirmed by an analysis of the variance of the figures tabulated in Table XIV, made by Mr. H. Herne of the B.I.S.R.A. Physics Department. He found that differences between the two scratches on a specimen have little effect on the reproducibility of test duration to failure, as compared with the effects due to type of finish or to differences in protective scheme.

Effect of Varying the Energy of the Blow Used to Produce the Impact Dome

In subsidiary tests four different impact domes were made on each specimen, using blows with energies of 10, 18, 26, and 34 in.-lb., respectively. Specimens representing industrial production were supplied through the courtesy of four collaborating firms, and included phosphated steel, both primed and primed and finished. All tests were made in

Fig. 4—Final appearance of specimens after 28 days in the C.R.L. Test. Top : Set N_2. Bottom : Set N_1.
Details of the protective schemes are given in Fig. 1.

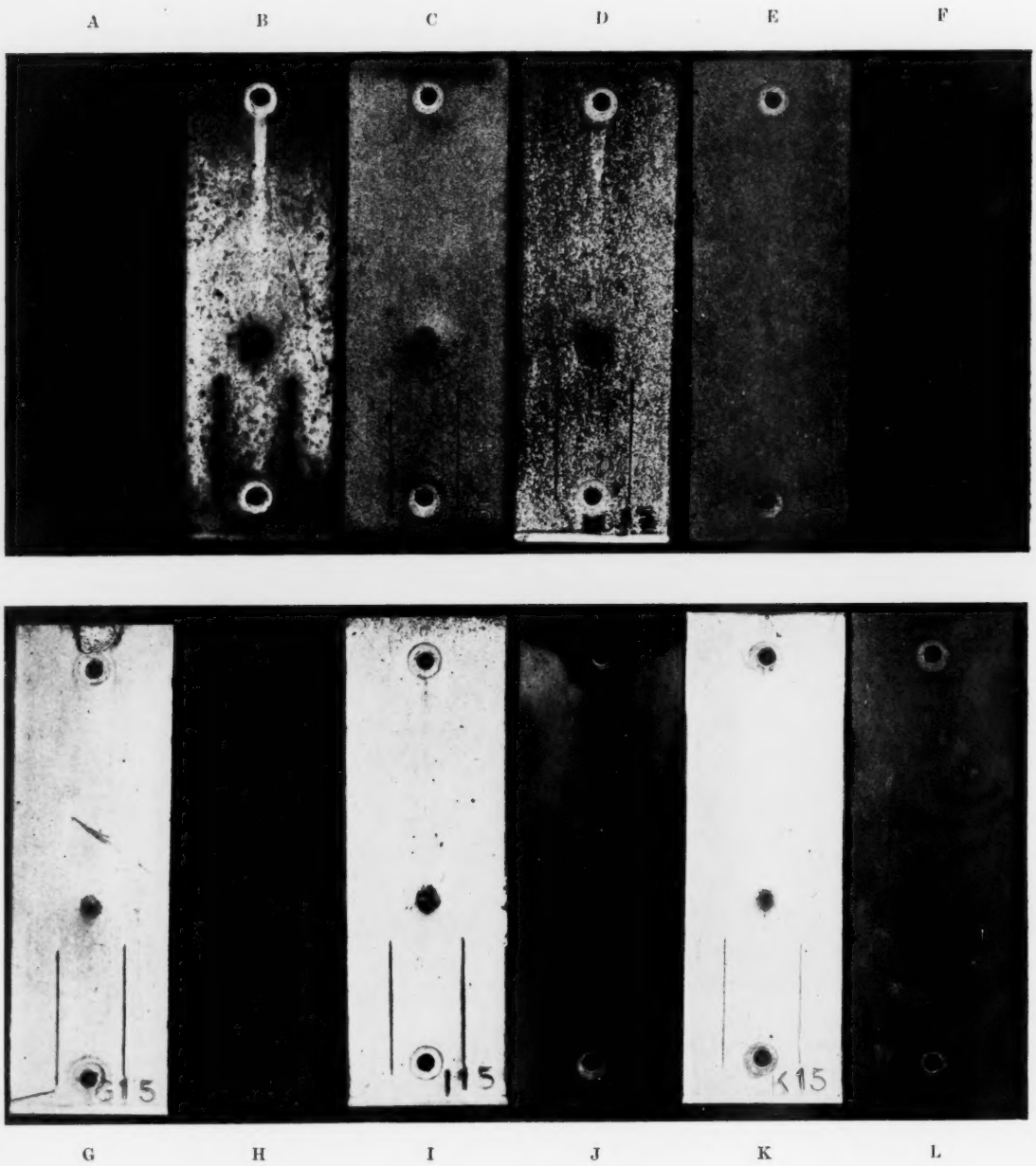
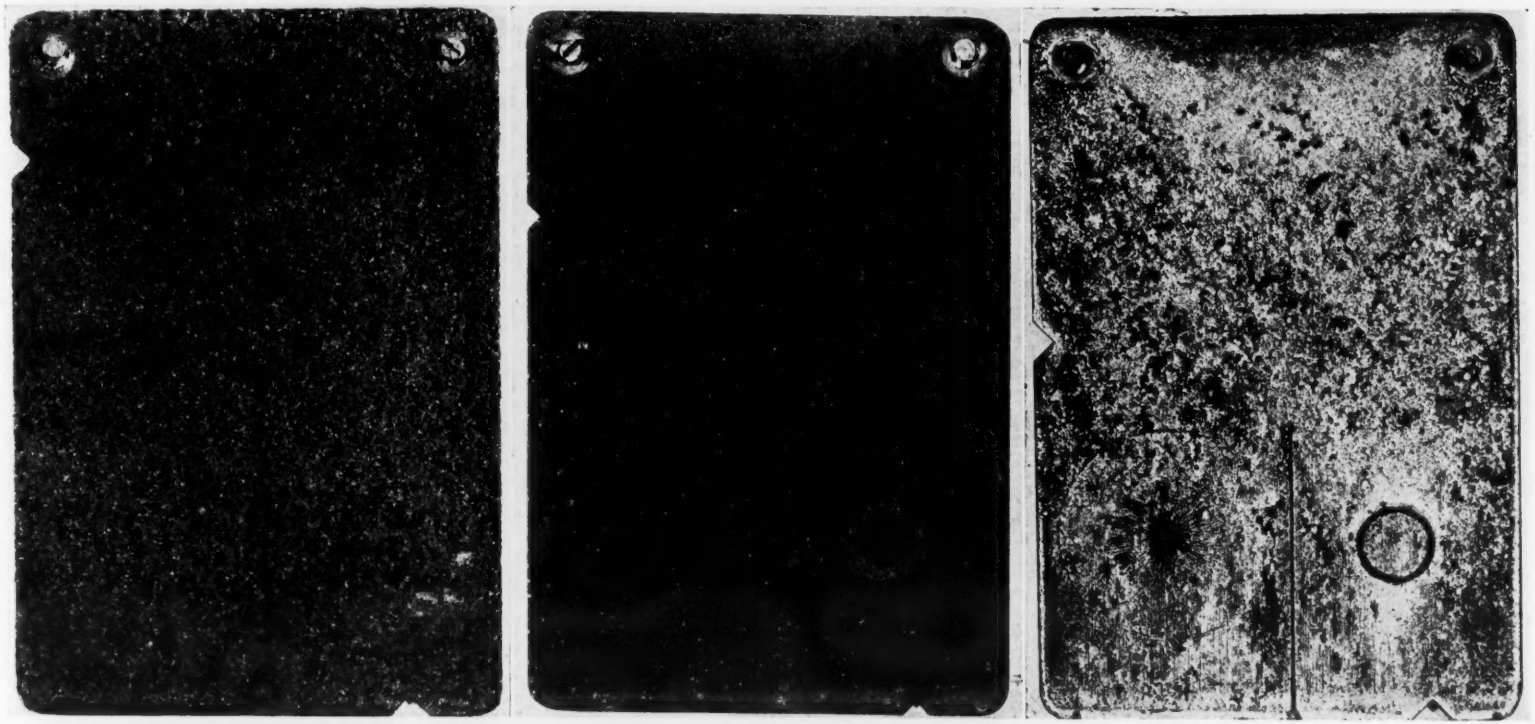


Fig. 5—Appearance of the specimens after one year's exposure at Slough (Laboratory T). Details of the protective schemes are given in Fig. 1

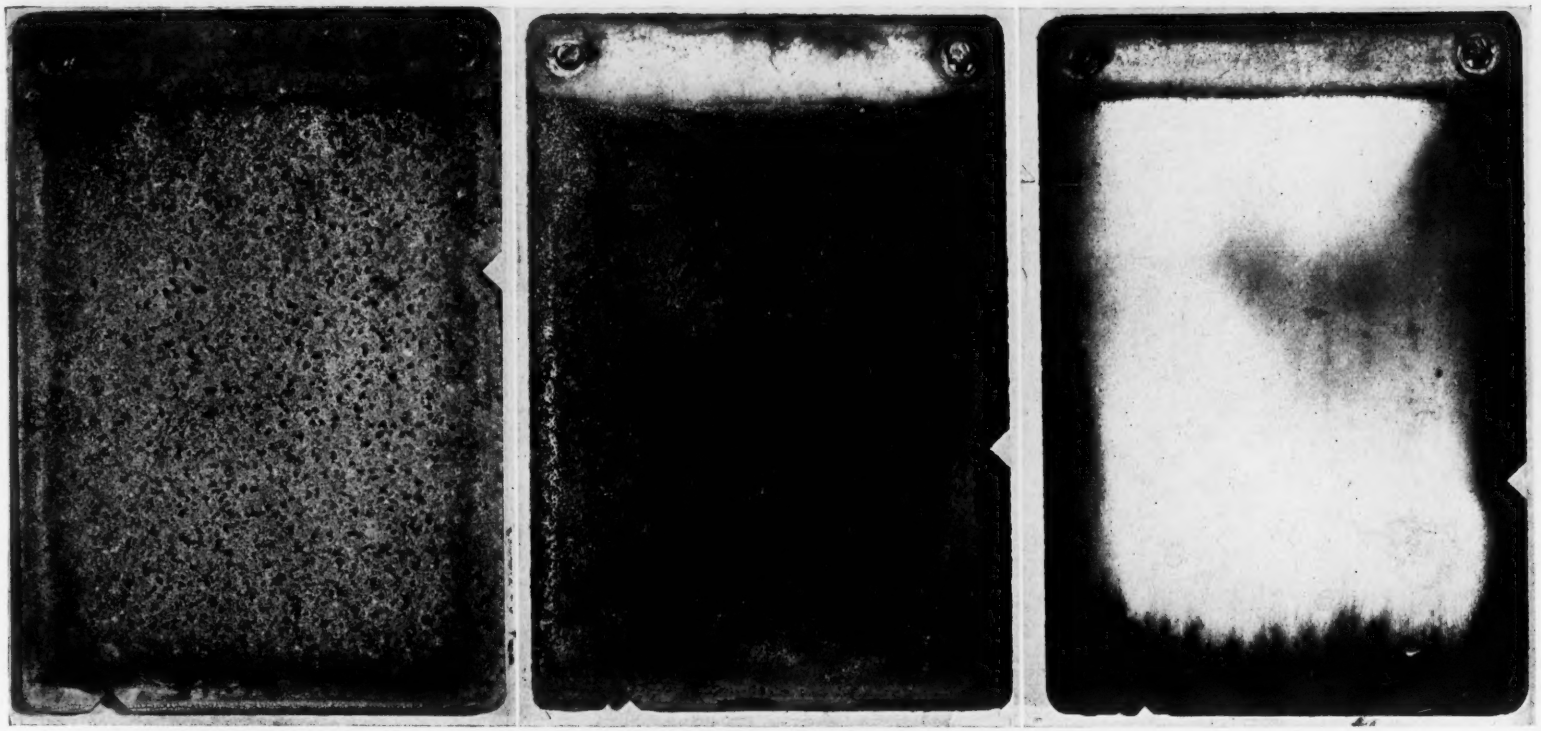
(a) (b) (c)



No. 1. Degreased, painted No. 3. Phosphated, painted No. 7. Pb electrodeposited 1 mil, painted

Fig. 6—Appearance of upper (freely-exposed) faces of specimens after five years' exposure in the field test at Birmingham. (*a*) and (*b*) show the benefits resulting from phosphating steel before painting. The non-phosphated specimen (*a*) is covered with coarse granular rust, which has obliterated the scratch and groove, whereas, although the paint on the phosphated specimen (*b*) has failed and is badly discoloured by rust staining, it is still affording the steel some protection. Little rusting has occurred on the lead-coated and painted specimen (*c*). The slight rusting near the top edge is due to imperfect plating. The paint film has cracked to some extent, probably from a catalytic effect of the lead during stoving. There has been practically no spread of rusting at the scratch and very little at the groove.

[Hudson



No. 5. Al sprayed 3 mils, painted

No. 11. Zn electrodeposited 0·3 mil, painted

No. 12. Zn electrodeposited, phosphated, painted

Fig. 7—Appearance of lower (sheltered) faces of specimens after five years' exposure in the field test at Birmingham. No mechanical damage other than the obverse of the impact dome was inflicted before exposure. The Al-sprayed and painted coating (*a*) has acquired a mottled and blistered appearance ; the blisters are about the size of pinheads, but no appreciable corrosion of the steel has occurred. The value of phosphating for preparing Zn-coated surfaces for painting is shown by specimens (*b*) and (*c*) ; the paint film has failed on both, but discolouration by rusting is much less evident on the phosphated coating (*c*).

Table XIV

DURATION OF TEST TO FAILURE AT THE SCRATCHES IN THE FIELD TEST, DAYS

Specimens from Firm No.	Position of Scratch (right or left)	Phosphated and Primed				Phosphated, Primed and Finished			
		1	2	3	Average	1	2	3	Average
1	R	98	98	119	105 ± 3	77	325	144	186 ± 30
	L	119	98	98		98	325	144	
2	R	144	165	98	124 ± 7	98	182	182	151 ± 11
	L	119	119	98		98	165	182	
3	R	98	98	98	98 ± 0	325	325	271	298 ± 8
	L	98	98	98		325	271	271	
4	R	144	165	165	135 ± 8	165	77	165	125 ± 12
	L	119	98	119		98	77	165	
5	R	325	325	325	318 ± 28	325	363	144	247 ± 28
	L	325	461	144		325	182	144	
6	R	56	21	77	40 ± 6	35	56	35	49 ± 5
	L	35	21	28		56	77	35	
7	R	165	165	35	170 ± 25	182	119	325	207 ± 26
	L	325	165	165		144	144	325	
8	R	98	182	98	126 ± 12	565	271	565	482 ± 36
	L	98	182	98		565	363	565	
9	R	144	77	56	92 ± 9	325	98	271	225 ± 26
	L	119	77	77		325	165	165	
Average					134				219

quadruplicate on 20 S.W.G. steel (0·036 in.), both in the laboratory and outdoors.

The results of the laboratory tests, described in the First Report, led to the conclusion that the best value for the energy of the blow was 18 in.-lb.; with this severity of blow a spread of breakdown not exceeding 0·25 in. after five days' spray test was considered permissible for specification purposes.

Table XV

RESULTS OF FINAL INSPECTION AFTER THREE YEARS' FIELD TEST: IMPACT DOME SERIES

Firm	Coating	Average Spread of Failure, × 0·01 in.							
		10 in.-lb. Dome		18 in.-lb. Dome		26 in.-lb. Dome		34 in.-lb. Dome	
		F	B	F	B	F	B	F	B
3	Phosphated and primed	12r	0	18r	0	20r	5r	22r	10r
	,, ,, finished	11r	0	15r	0	19r	0	20r	0
4	,, ,, primed	16r	...*	20r	...*	23r	10r	28r	24r
	,, ,, finished	18r	0	21r	0	28r	10r	32r	16r
5	,, ,, primed	...*	0	...*	0	...*	0	...*	0
	,, ,, finished	21rb	1b	30rb	16r	32rb	35rb	35rb	28rb
7	,, ,, primed	23r	0	29r	0	24r	0	36r	6r
	,, ,, finished	11r	0	16r	0	21r	0	23r	0

* Indeterminate owing to general rust-staining of the surfaces
r = failed by rusting
b = failed by blistering

Table XVI

TEST DURATION TO FAILURE AT THE IMPACT DOME IN THE FIELD TEST, DAYS

Average of four specimens

Specimens from Firm No.	Spread of Breakdown for Failure, × 0·01 in.	Phosphated and Primed				Phosphated, Primed, and Finished			
		10 in.-lb.	18 in.-lb.	26 in.-lb.	34 in.-lb.	10 in.-lb.	18 in.-lb.	26 in.-lb.	34 in.-lb.
3	15	>1098	386	43	7	>1098	577	292	76
	20	>1098	>892	459	220	>1098	>1098	>1018	583
	25	>1098	>1098	>1098	>892	>1098	>1098	>1098	<1098
4	15	>704	187	19	12	114	7	7	7
	20	>910	454	318	143	>1098	307	35	7
	25	>1098	>871	>516	345	>1098	>1098	347	177
5	15	>274	>192	171	16	190	173	145	113
	20	>274	>289	>421	215	199	173	190	173
	25	>274	>289	>427	>253	345	209	199	190
7	15	238	209	190	144	>704	>495	271	165
	20	493	239	227	218	>812	>681	320	289
	25	>1046	498	257	239	>949	>910	436	467

The field-test specimens were exposed for three years, when the spread of failure from the various types of dome was as shown in Table XV. The durations of test to failure for the various combinations of protective scheme and energy of blow are tabulated in Table XVI; three series of values have been calculated corresponding to spreads of failure from the centre of the dome of 0·15, 0·20, and 0·25 in., respectively.

The most revealing method of dealing with these results is to express the total number of specimens passing the test for each value of the permissible spread of failure as a function of the energy used to produce the dome. This is done in Table XVII on a percentage basis both for the field test over three years and for the A.R.E. test over five days; in the latter case the results are the mean values from two laboratories.*

The main conclusion drawn from the figures given in Table XVII is that the correlation between the behaviour of protective schemes at the domes in the field and the laboratory tests is good. The correlation coefficient between the values shown in the third and fourth columns of the table is 0·98.

The figures given in Table XVII cannot be used to compare the rates of breakdown at the dome in the laboratory tests and in the field tests. The acceleration of breakdown at the dome achieved in the laboratory test seems to be of the order of one hundred times, because, as shown in Table XVI, the life to failure in the field test exceeded three years for many specimens.

Significance of Behaviour at the Impact Dome in the Interpretation of the Results

When considering the original draft of Provisional B.S. 1391 (1947), the Sub-Committee endeavoured to choose the criteria of failure in such a way that failure in the test was equally likely to occur on the undamaged surface or at the seats of damage.* The data presented in the last section may be used to ascertain how far this object has been achieved in respect of the impact dome, by recording the number of cases in which failure there preceded or followed failure on the undamaged surface or at the scratches. This is done in Table XVIII, which refers to the field tests (*see* Table XVI). For the procedure specified in Provisional B.S. 1391 (1947)—energy of blow, 18 in.-lb., permissible spread of failure, 0·25 in.—behaviour at the dome has had little effect in determining failure of the protective scheme. To make the

* First Report: *loc. cit.*, p. 489.

Table XVII

PERCENTAGE OF PASSES FOR VARIOUS PERMISSIBLE SPREADS OF FAILURE AT DOMES PRODUCED BY BLOWS OF DIFFERENT ENERGIES

Energy of Blow, in.-lb.	Permissible Spread of Failure, × 0·01 in.	Domes Passing the Test,* %	
		Field Test (3 years)	Laboratory Test (5 days)
10	15	31	52
	20	53	81
	25	81	95
18	15	13	25
	20	34	59
	25	56	86
26	15	0	9
	20	6	41
	25	41	73
34	15	0	2
	20	3	28
	25	31	55

* Relating to 32 domes in the field test and to 64 domes in the laboratory test (pooled results for two laboratories)

* The third laboratory referred to in the First Report did not conduct laboratory tests on the full range of specimens.

Table XVIII

FREQUENCY WITH WHICH FAILURE OCCURRED FIRST AT THE IMPACT DOME (OUT OF 8)

Energy of Blow, in.-lb.	Permissible Spread of Failure 0·15 in.	0·20 in.	0·25 in.
10	1	1	0
18	2	1	1
26	4	2	1
34	7	2	1

influence of the dome equivalent to that of the other criteria of failure, it would be necessary either to increase the severity of the blow or to reduce the permissible spread of breakdown.

Conclusions

The following conclusions may be drawn from this work :

(i) Laboratory tests, carried out in accordance with Provisional B.S. 1391 (1947), on stoving paints applied to phosphated steel have given good correlation with the results of outdoor exposure tests. The value of the A.R.E. test for protective schemes of this type may, therefore, be regarded as established.

(ii) Analysis of the observations made at the scratches on specimens exposed outdoors for three years has shown that failure at the scratches is reproducible. It may therefore be concluded that the scratch is a useful form of damage and that the criteria of failure at the scratch laid down in Provisional B.S. 1391 (1947) are suitable.

(iii) Failure at the dome, using the test conditions specified in Provisional B.S. 1391 (1947), is not a determining factor for failure in outdoor exposure tests of protective schemes comprising phosphating and stoving paints. Most protective schemes of this type withstand the standard blow without suffering serious breakdown on subsequent exposure. If the impact dome is to be retained in the test, it would be desirable either to increase the energy of the impact blow or to reduce the permissible spread of failure.

FURTHER INTERIM RESULTS OF THE FIELD TEST UNDERTAKEN IN CONNECTION WITH THE GENERAL INVESTIGATION OF LABORATORY TESTS

Introduction

The earlier work of the Sub-Committee was mainly concerned with investigating the value of seven different types of laboratory test for protective schemes applied to steel.* The comparison was made by subjecting standard sets of 15 specimens coated with different protective schemes to each laboratory test and correlating the results with those observed for a similar set of specimens exposed to atmospheric corrosion outdoors. At the time the First Report was written all the laboratory tests had been completed, but the field test, then 1·5 years old, was still in progress, so that the correlation made in that Report was a provisional one. Field-test results are now available for a period of five years, and so it is opportune to reconsider the correlation between the laboratory tests and the field test. This correlation is still provisional, because all the protective schemes have not yet failed in the field test.

* First Report : *loc. cit.*, pp. 465–477.

Results of the Field Test up to Five Years' Exposure

The results obtained in the field test up to five years' exposure are summarized in Tables XIX and XX. The specimens measure 6 in. × 4 in. × 20 S.W.G. ; the protective coatings on them were damaged by means of a scratch, an impact blow (dome), and a machined groove before the test commenced. They were exposed at 45° facing south in an urban atmosphere at Birmingham.

The severity of the atmospheric conditions may be judged from the rates of corrosion of bare ingot iron and zinc specimens, exposed vertically in the vicinity, which averaged 4·0 and 0·14 mils/year respectively over four separate periods of one year between 1946 and 1950. These rates correspond roughly to an annual loss of 27 g. for mild steel or 0·8 g. for zinc per year for 6-in. × 4-in. × 20 S.W.G. specimens.

The appearance of the specimens after five years' exposure is described in Table XIX, in which their changes in weight after 5¼ years are also given. These changes are the differences between the weights of the specimens then and their weights in the fully coated condition before exposure. The average weight of the dry paint film on the painted specimens was 2·0 g.

Too much significance should not be attached to these weight changes, although they are a useful check on the performance of the protective scheme. For example, the absence of any marked loss in weight of the lead-coated specimens 6 and 8 is a further indication of the good performance of these protective schemes. Moreover, the small gain in weight of the phosphated and painted specimen 3 shows that its performance was better than appeared at first sight. On this specimen rust stain was mistaken for rust at the early inspections. It has, therefore, been upgraded and its 'life,' given at 190 days in the First Report, is now estimated to have been 1829 days on the front and 1740 days on the back.

The losses in weight of the unpainted zinc specimens 10, 13, and 15 are also significant. The average figure for the two heavier coatings, 13 and 15, is 2·0 g. This is of the same order as the weight of the zinc coating on the former specimen (5·6 g.), but considerably less than the weight on the latter (18 g.). The observations that the zinc coating is intact on specimen 15 but has failed on the back of specimen 13 agree with these facts. Moreover, the thin zinc coating on specimen 10 failed after 2·3 years, and this specimen has since suffered a substantial loss in weight. The sprayed aluminium coatings 4 and 5 have increased in weight ; this may be due to corrosion of the aluminium coating itself. A similar bare steel control specimen, the exposure of which is being continued, lost 27 g. This loss corresponds to an average rate of rusting of about 2 mils/year ; the loss would naturally have been greater had the specimen been de-rusted.

Table XX also gives figures for the percentages of rust on the specimens after five years and the lives to failure by general rusting. The point of failure has been taken as 1% of rust, which is the next grade

beyond the permissible limit of 0·5% of rust specified in Provisional B.S. 1391 (1947). Values are given for both the fronts and backs and relate to the upper undamaged halves of the specimens, excluding the specified margin of $\frac{3}{8}$ in. allowed round the edges.

Only one additional protective scheme has failed since the publication of the First Report. This is protective scheme 13 (zinc electrodeposited, 1 mil), which had just failed on the back surface after five years. On the other hand, with the exception of scheme 3 (phosphated, painted), all the protective schemes that were stated in the First Report to have failed have deteriorated during the ensuing three years.

Although these tests were not undertaken to compare the merits of the various protective schemes it is of interest to note the two main features of the figures in Table XIX. First, the marked improvement resulting from phosphating bare steel before painting it is shown by a comparison of specimens 3 and 1. The behaviour of the gritblasted and painted specimen 2 is not representative, because the paint film was insufficiently thick in relation to the roughness of the gritblasted surfaces and did not, therefore, adequately cover high spots. Secondly, the protective schemes including a heavy metallic coating, *i.e.*, aluminium sprayed, 3 mils (4 and 5); lead electro-

Table XIX

CONDITION OF THE PROTECTIVE SCHEMES AFTER FIVE YEARS' EXPOSURE AT BIRMINGHAM

Protective Scheme*		Change in Weight after 5½ Years' Exposure, g.	Condition after 5 Years' Exposure					
No.	Description		Front	Back	Rusting, %		Duration of Test to 1% Rusting, days†	
					Front	Back	Front	Back
1	Degreased, painted	−2·8	Rust, rust stain, and flaking all over	Rust stain all over; rust and flaking from edges	100	40	117	190
2	Gritblasted, painted	−0·4	Rust, rust stain, and flaking all over	Rust stain all over; rust and flaking from edges	100	20	46	78
3	Phosphated, painted	+0·1	Rust stain all over; rust and flaking from scratches and edges	Rust stain all over; rust from edges	1	1	1829	1740
4	Al sprayed, 3 mils	+1·3	Blistering all over	Blistering all over	0	0·1	—	—
5	Al sprayed, 3 mils, painted	+0·3	Blistering and paint eroding all over	Rust-spotting all over; paint cracking at edges	0	0·5	—	—
6	Pb, electrodeposited, 1 mil	−0·1	Rust stain from top edge and scratches, otherwise intact	Rust stain from edges; otherwise intact	0·5	0·5	—	—
7	Pb, electrodeposited, 1 mil, painted	−1·5	Rust stain from top edge; paint cracking and eroding; otherwise intact	Rust stain from edges; paint cracking; otherwise intact	0·2	0	—	—
8	Pb, electrodeposited, 3 mils	0·0	Rust stain from top edge, otherwise intact	Rust stain from edges, otherwise intact	0·5	0·2	—	—
9	Zn, electrodeposited, 0·05 mil, phosphated, painted	−0·4	Rust stain all over; rust and flaking from top edge and scratches	Rust stain all over; rust and staining from edges, especially at the top	80	5	190	1287
10	Zn, electrodeposited, 0·3 mil	−8·1	Rust and flaking all over	Coating corroded away round edges	100	40	738	1240
11	Zn, electrodeposited, 0·3 mil, painted	−6·6	Rust and flaking all over	Rust and flaking all over	100	100	563	1418
12	Zn, electrodeposited, 0·3 mil, phosphated, painted	−4·4	Rust and flaking all over	Rust and flaking at edges; rust stain all over	100	2	462	1467
13	Zn, electrodeposited, 1 mil	−2·1	Rust stain at edges, otherwise intact	Rust and rust stain spreading from edges	0·1	2	—	1829
14	Zn, electrodeposited, 1 mil, painted	−3·1	Paint eroding and cracking all over; rust stain at edges; zinc coating otherwise intact	Paint flaking from edges; rust stain from top edge; zinc coating otherwise intact	0·2	0·2	—	—
15	Zn, hot-dipped, 3 mils	−1·9	Intact	Intact	0	0	—	—
16	Zn, hot-dipped, 3 mils, painted	−3·6	Paint eroding and cracking all over; rust stain from edges and suspension holes; zinc coating otherwise intact	Paint flaking from edges; zinc coating otherwise intact	0·1	0	—	—

* The approx. wts. of original coatings in g. per specimen were:

No. 3 (Phosphate)	0·2	No. 8 (Pb)	24	No. 12 (Zn : Phosphate)	1·7 : 0·1
Nos. 4 and 5 (Al)	7	No. 9 (Zn : Phosphate)	0·3 : 0·1	Nos. 13 and 14 (Zn)	5·6
Nos. 6 and 7 (Pb)	9	Nos. 10 and 11 (Zn)	1·7	No. 15 (Zn)	18

The dry paint film on painted specimens weighed approx. 2·0 g.

† A dash indicates that this degree of rusting had not been reached after 1829 days' rusting

deposited, 1 mil (6, 7, and 8), and zinc hot-dipped, 3 mils (15 and 16), have remained intact for five years, whether painted or not. The performance of the lead coatings, which are only 1 mil thick, is outstanding.

The condition of these metal coatings is thus that 15 and 16 (zinc hot-dipped, 3 mils) are still protecting the steel perfectly; the remainder are in good condition except for some blistering of the sprayed aluminium coatings (4 and 5), some rust stain on the electrodeposited lead coatings (6, 7, and 8), and some rust at the edges of specimens 13 and 14 (zinc electrodeposited, 1 mil). On the painted specimens the paint has chalked considerably and most of it has been eroded from the front surfaces. The paint seems to have chalked less over a lead coating than over aluminium or zinc coatings.

Representative photographs of some of the specimens after five years are shown in Figs. 6 and 7.

The order of merit of the 16 protective schemes deduced from the behaviour at the seats of damage as well as over the undamaged area has varied considerably throughout the tests (Table XX). The correlation coefficient between the order after 1·5 years, used in the First Report for comparison with the laboratory tests, and the order after five years is only 0·59. Protective schemes 5 (aluminium sprayed, 3 mils, painted), 15 (zinc hot-dipped, 3 mils), and 16 (zinc hot-dipped, 3 mils, painted) show to much better advantage after five years than after six months, but the unpainted and painted coatings of electrodeposited zinc, 0·3 mils (10, 11, and 12) have fallen considerably in the order of merit.

Correlation of the Field Test with the Various Laboratory Tests

The individual tests considered in this investigation were as follows:

(*A*) Field test (atmospheric exposure) at Birmingham
(*B*) Humidity cabinet (C.C.I.)
(*C*) Sea-water spray (one spraying each day)
(*D*) 20% NaCl spray (continuous)
(*E*) Acidified sea-water spray plus accelerated weathering
(*F*) Intermittent spray test
(*G*) Humidity plus SO_2
(*H*) Water spray plus SO_2
(*I*) Accelerated weathering plus SO_2

In Table III of the First Report correlations between the respective laboratory tests after varying testing periods and the field test (*A*) were calculated from the order of merit in the field test after 1·5 years' exposure. These correlation coefficients have now been recalculated using the ranking order in the field test for five years given in Table XX. The results are compared in Table XXI, with the correlation coefficients based on the order of merit after 1·5 years' field test; in the latter case, the single correlation coefficient is that for the duration of laboratory testing giving the best fit with the results of the field test.

The 5-year correlation coefficients do not agree well with those for 1·5 years. The worst discrepancies occur for Test *C* (sea-water spray—the A.R.E. test) and Test *I* (accelerated weathering plus SO_2). For Test *C* the correlation after five years' field test is worse, but for Test *I* it is better.

As already remarked, the order of merit of different protective schemes is not fixed but varies with the conditions and duration of exposure. These variations in the correlation coefficients do not necessarily mean, therefore, that one laboratory test is better or worse than another, but rather that each may be more suitable for a particular purpose. For example, if in the present results the correlation is limited to protective schemes 1, 2, 3, 9, 10, 11, and 12, which do not include a heavy metallic coating and have all failed within the five years, the values of the correlation coefficients become as shown in Table XXI. These figures indicate that, in general, tests *E*, *F*, *G*, *H*, and *I*, all of which use sulphur dioxide or sulphuric acid, give much better correlation with the results of the field test after 5 years than after 1·5 years. On the other hand the results of the laboratory tests by

Table XX

ORDER OF MERIT OF THE PROTECTIVE SCHEMES AFTER VARIOUS PERIODS OF EXPOSURE

No.	Protective Scheme	Duration of Exposure, years						
		0·5	1	1·5	2	3	4	5
1	Degreased, painted	15	16	16	16	16	15	14
2	Gritblasted, painted	16	15	15	15	13	11	13
3	Phosphated, painted	14	14	14	14	10½	10	10
4	Al, sprayed, 3 mils	2	6	3½	6	5	4	2
5	,, ,, ,, painted	12	9	6	8	8	5½	4
6	Pb, electrodeposited, 1 mil	13	12	10	7	7	9	9
7	,, ,, ,, painted	11	10	8½	5	6	7	5
8	,, ,, 3 mils	7½	13	13	10	9	8	6½
9	Zn, ,, 0·05 mil, phosphated, painted	10	11	12	12	10½	12	11
10	,, ,, 0·3 mil	2	1	8½	9	15	16	15
11	,, ,, ,, painted	4	4½	7	11	14	14	16
12	,, ,, ,, phosphated, painted	7½	4½	11	13	12	13	12
13	,, ,, 1 mil	2	8	5	1	2	3	6½
14	,, ,, ,, painted	5	3	2	3	4	5½	8
15	,, hot-dipped, 3 mils	6	2	1	2	1	1	1
16	,, ,, ,, painted	9	7	3½	4	3	2	3

Table XXI

CORRELATION OF LABORATORY TESTS AFTER VARIOUS DURATIONS OF TEST WITH THE RESULTS OF THE FIELD TEST

Humidity Cabinet *B*		Sea-water Spray *C*		20% Salt Spray *D*		Acidified Sea Water + Accelerated Weathering *E*		Intermittent Spray *F*		Humidity + SO_2 *G*		Water Spray + SO_2 *H*		Accelerated Weathering + SO_2 *I*	
Days	ρ	Days	ρ	Days	ρ	Days	ρ	Days	ρ	Days	ρ	Days	ρ	Days	ρ
ALL COATINGS															
Field Test 5 Years															
7	0·58	4	0·32	10	0·17	10	0·31	60	0·85	25	0·10	17	0·18	6	0·48
27	0·58	11	0·33	22	0·33	35	0·78			52	0·07	101	0·60	13	0·62
76	0·69	21	0·38	55	0·58					101	0·11	205	0·78	41	0·79
		28	0·28	87	0·63					143	0·28	380*	0·87	81	0·71
Field Test 1·5 Years															
7	0·94	21	0·78	87	0·51	35	0·41	60	0·58	25	0·49	205	0·83	27	0·46
SHORT-LIFE COATINGS†															
Field Test 1·5 Years															
7	0·88	4	0·72	10	0·68	10	0·32	60	−0·32	25	0·68	17	0·93	6	0·04
27	0·85	11	0·72	22	0·57	35	0·21			52	0·57	101	0·36	13	−0·11
76	0·37	21	0·86	55	0·39					101	−0·32	205	0·46	41	−0·75
		28	0·85	87	0·57					143	−0·25	380	0·00	84	−0·86
Field Test 5 Years															
7	−0·29	4	0·07	10	0·14	10	0·49	60	0·75	25	−0·07	17	−0·36	6	0·61
27	−0·26	11	0·07	22	0·28	35	0·59			52	0	101	0·21	13	0·68
76	0·12	21	−0·27	55	0·46					101	0·82	205	0·07	41	0·68
		28	−0·19	87	0·28					143	0·82	380	0·71	84	0·63

* Gross period 645 days † Nos. 1, 2, 3, 9, 10, 11, and 12

methods *B*, *C*, and *D*, in which no sulphur dioxide is used, agree much better with those of the field test over the shorter period. It may, therefore, be found that tests incorporating sulphur dioxide, such as the C.R.L. test, are more suitable for the more durable protective schemes (*e.g.*, the thicker metallic coatings), whereas tests such as the A.R.E. test, which do not use sulphur dioxide, are more readily applicable to coatings with a shorter life, such as stoving paints.

SUMMARY

(i) A new laboratory test, the C.R.L. sulphur dioxide test, for assessing resistance to corrosion, has been applied to a range of protective schemes for mild steel. It has proved satisfactorily reproducible in different laboratories and has given fair correlation with the results of outdoor atmospheric exposure tests.

(ii) The C.R.L. test should form a useful addition to Provisional British Standard 1391 (1947).

(iii) The results of outdoor tests on industrial protective schemes embracing stoving paints confirm the conclusion that the A.R.E. salt droplet test gives a reasonable indication of the service performance of this type of protective scheme under such conditions.

(iv) The reproducibility of the breakdown of protective schemes at scratches inflicted as specified in Provisional B.S. 1391 (1947) is adequate.

(v) Satisfactory agreement was observed between the performance of protective schemes at the impact dome specified in Provisional B.S. 1391 (1947), when subjected to the A.R.E. test and to outdoor exposure, respectively. If, however, observations at the impact dome are to be made of equal significance in determining failure with those at the scratches or on the undamaged surface, it will be necessary to increase the severity of the blow or to reduce the permissible spread of failure from the dome.

(vi) Interim results, for five years' exposure, are presented for the original field test undertaken by the Sub-Committee. The correlation between the results of the laboratory tests that do not involve the use of sulphur dioxide and the results of the field test is less after 5 years than after 1·5 years.

(vii) Preliminary attention has been paid to methods for the removal after test of corrosion products from mild-steel specimens carrying protective schemes of metallic coatings, with or without paint.

Acknowledgments

The Sub-Committee has pleasure in acknowledging its indebtedness to the following firms and institutions for the supply of materials or services :

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APPENDIX

Methods for Stripping Paint and Removing Corrosion Products from Steel Test Specimens Carrying Protective Coatings

It is usual at the end of a corrosion test to remove the corrosion products from the specimens so as to determine their losses in weight through corrosion. This removal is generally a simple matter for bare specimens, but may present difficulties when the specimens carry protective schemes. It may, therefore, be of interest to describe the methods of cleaning used for the specimens subjected to the tests described in the first section. These specimens had been coated with a wide range of protective schemes (*see* Fig. 1), and the following procedures were suggested for cleaning them after test.

Suggested Methods for the Final Cleaning of the Specimens

Removal of Paint—Where paint forms part of the protective scheme, remove the paint first by soaking the specimens in methylene chloride, which should cause the paint to blister and flake off readily. Methylene chloride is volatile and should be used with care.

Bare Steel (*A*)—Use the method specified in Provisional B.S. 1391 (1947) : de-rust in Clarke's solution, which consists of 2 parts of antimonious oxide and 5 parts of stannous chloride, dissolved in 100 parts of concentrated hydrochloric acid. Use the solution cold and keep the specimen moving until the de-rusting is complete. Then wash the specimen well in cold water, dry, and weigh.

Phosphated and Painted (*B*)—Remove the paint and then de-rust in Clarke's solution as for specimen *A*.

Aluminium-Sprayed, 3 mils (*C*)—Immerse for 10-min. periods in an aqueous solution containing 2% of chromic acid and 5% of phosphoric acid, heated to 80–85° C. Wash, dry, and weigh after each immersion until the weight loss is constant. Include a blank specimen in the determination.

Aluminium-Sprayed, 3 mils, Painted (*D*)—Remove the paint and then proceed as for specimen *C*.

Solid Aluminium, Gritblasted, Aluminium-Sprayed, 5 mils (*E*)—As for specimen *C*.

Lead-Electrodeposited, 1 mil (*F*)—Use the following solution :

120 ml. of water
100 ml. of glacial acetic acid
100 ml. of ammonia 0·880

The solution is prepared by adding the glacial acetic acid to the water and then pouring in the ammonia. Both operations should be conducted slowly, so as to avoid an excessively rapid evolution of heat.

Boil the solution for a few minutes to remove any dissolved air and then immerse the specimen in the boiling solution. Remove the specimen about 15 sec. after gassing has ceased. Wash the specimen in cold water, rinse in alcohol and acetone, and dry in warm air.

Lead Electrodeposited, 1 mil, Painted (*G*)—Remove the paint and then proceed as for specimen *F*.

Tin Electrodeposited, 0·1 mil (*H*)—Remove the rust and tin corrosion products by cathodic treatment in the cold (below 30° C.), using 1% sodium carbonate solution. Use steel or nickel anodes placed opposite both faces of the specimen and a current density of about 30 amp./sq. ft., on each surface ; this current density should be given by an applied voltage of 8 V. Throughout the treatment rub the specimen down to remove the corrosion products. When removal is complete, after about 10 min., wash and dry the specimen.

Tin Electrodeposited, 0·1 mil, Filmed, Painted (*I*)—Remove the paint and then proceed as for specimen *H*.

Zinc Electrodeposited, 0·1 mil (*J*)—Place the specimen as the cathode in 10% potassium cyanide solution, the anode being a cylinder of iron gauze surrounding the specimen. Use a current density of from 20–200 amp./sq. ft. Alternate $\frac{1}{2}$–$\frac{3}{4}$ min. treatments in the potassium cyanide bath with scrubbing under water, using a bristle brush. Do not immerse the specimen in the cathodic cleaning bath without the current flowing. Include a blank with the determination.

Zinc Electrodeposited, 0·1 mil, Phosphated, Painted (*K*)—Remove the paint and then proceed as for specimen *J*.

Solid Zinc, Gritblasted, Zinc-Sprayed, 5 mils (*L*)—As for specimen *J*. The loss in weight of the blank specimen may be higher than for specimen *J* owing to the greater surface of the sprayed zinc coating on specimen *L*.

Results

The procedures described above and in some cases alternative cleaning methods were applied to sets of specimens in each of seven different laboratories. The main observations made are summarized below.

Removal of Paint—It proved difficult to remove the stoved paint film by means of methylene chloride. The treatment was satisfactory for specimen *G* (lead electrodeposited, 1 mil, painted) and also in some cases for specimen *B* (phosphated, painted), but methylene chloride did not affect the paint film on specimens *D*, *I*, and *K* (aluminium, tin, and zinc-coated, respectively) even after 2 or 3 days' soaking. Other methods for removing the paint film were tried as follows :

Table XXII

AVERAGE LOSSES IN WEIGHT* OF THE SPECIMENS IN THE LABORATORY TESTS AFTER CLEANING, GRAMMES

	Protective Scheme	C.R.L. Test	A.R.E. Test
A	None: bare steel	3·4	3·2
B	Phosphated, painted	0·1	0·1
C	Al, sprayed, 3 mils	0·1	0·2
D	Al, sprayed, 3 mils, painted	−0·1	−0·1
E	Al, sprayed, 5 mils, over Al	0·1	0·1
F	Pb, electrodeposited, 1 mil	1·5	0·4
G	Pb, electrodeposited, 1 mil, painted	0·3	0·2
H	Sn, electrodeposited, 0·1 mil	0·2	0·1
I	Sn, electrodeposited, 0·1 mil, filmed, painted	0·0	0·0
J	Zn, electrodeposited, 0·1 mil	1·6	0·2
K	Zn, electrodeposited, 0·1 mil, phosphated, painted	0·1	0·0
L	Zn, sprayed, 5 mils, over Zn	0·5	0·2

* Steel and/or metallic coating: total surface area 24 sq. in.

(i) Boiling in alcohol. This caused the paint to blister

(ii) Immersion in a hot solution of 10% of phenol and 10% of paraffin wax in trichlorethylene. The specimens were periodically scraped to remove the paint; finally the wax was removed by holding the specimens in trichlorethylene vapour. This method removed the paint from all the specimens, removal being most difficult for specimen *D* (sprayed aluminium, 3 mils, painted)

(iii) Boiling in 10% caustic soda. This could not be used for specimens *D*, *G*, and *K* because caustic soda attacks aluminium, lead, and zinc. Caustic soda does not attack tin, however, if a reducing agent is present and under such conditions the method might be suitable for painted tin coatings

(iv) Heating specimens in molten β-naphthol at 200° C. This removed the paint satisfactorily from specimens *D* and *K*, but it could not be used for specimen *G* as it attacks lead. The method gives rise to considerable fumes and suitable operating technique is necessary to deal with this aspect

(v) Boiling overnight under a reflux condenser with 50 : 50 ethyl acetate : butyl alcohol. This removed the paint satisfactorily from all the painted specimens

(vi) Soaking in butyl cellosolve and rubbing. This removed the paint from specimens *B*, *G*, and *I* only

(vii) Boiling in a cresol-type paint stripper. This removed the paint satisfactorily from all the painted panels. This stripper was not used on the lead-coated panels, as it was thought that it might attack lead.

Specimens A (Bare Steel) and B (Phosphated and Painted)—The use of Clarke's solution for removing rust has been proved satisfactory by long experience. As it removed both the phosphate coating and the rust from specimen *B* a correction for the weight of the phosphate coating was necessary when calculating the loss of steel.

Specimens C, D, and E (Aluminium-Sprayed)—The suggested method was not satisfactory as it was difficult to obtain an end point, *i.e.*, the weight of the specimens decreased after each successive immersion. Some of the specimens turned black during immersion in chromic and phosphoric acids. It has been suggested that cold 70% nitric acid could be used for aluminium-coated specimens.

Specimens F and G (Lead Electrodeposited)—The suggested method removed the lead corrosion products satisfactorily, but it did not easily remove the rust present on some specimens. The cathodic treatment suggested for tin was used in one laboratory to remove the remaining rust from the lead-coated specimens; a blank of sheet lead was not attacked by this treatment.

Specimens H and I (Tin Electrodeposited)—The method worked satisfactorily. The immersion and rubbing down had to be repeated several times to remove deep-seated rust.

Specimens J, K, and L (Zinc Electrodeposited (J and K) and Sprayed (L))—The method worked satisfactorily, although it was difficult to remove deep-seated rust present on some of the specimens. As these badly corroded specimens had no zinc coating remaining on them, Clarke's solution was used to remove the remaining rust in several laboratories. Blanks of sprayed zinc only suffered a slight loss in weight in the cathodic cleaning bath.

Conclusions

The object of this work was to determine the true loss in weight of the specimen, *i.e.*, loss of metallic coating plus loss of steel, if any. This object was not always achieved, because in some cases the deep-seated rust present could not be removed by the method suggested for removing the corrosion products of the metallic coating. Where a specimen is badly corroded it may, therefore, be preferable to remove the metallic coating completely together with the rust from the basis steel. This might be done by means of an inhibited mineral acid, which would remove most of the common metallic coatings and also the rust. The loss of steel could be calculated from the final weight of the specimen and its known weight before the application of the metallic coating.

The average losses in weight (steel plus metallic coating, if any) of the specimens in both laboratory tests, after cleaning by the methods described, are given in Table XXII. The figures relate to up to eight determinations made in different laboratories; the individual values agreed fairly well. Three sets of specimens were cleaned in the same laboratory. The correlations between average losses in weight of the three sets and the average gains in weight were 0·60 for the C.R.L. test and 0·58 for the A.R.E. test.

Except for bare steel and the specimens with unpainted zinc or lead coatings the losses in weight were small and call for no comment.

A Recording Dust Meter

By B. O. Smith, B.Sc., A.Inst.P., and S. S. Carlisle, M.Sc., A.M.I.E.E.

SYNOPSIS

A knowledge of dust levels in industrial gases is of considerable importance in the efficient operation of gas-producing and gas-consuming plant. The method most commonly used in the steel industry for estimation of the dust content of blast-furnace or coke-oven gas involves the weighing of a filtering medium on which a dust sample has been deposited. This technique will give a mass concentration measurement integrated over a relatively long period but is incapable of providing a continuous record. The instrument described in this paper gives a continuous record which, in certain cases, is directly related to the mass concentration but generally is a qualitative measure of the dust level. It uses a light-scattering technique in which a photoelectric cell measures the light scattered by dust particles in a direction normal to the illuminating beam. The scattered light flux, inferred from the photocell current, is taken as a measure of dust concentration.

The paper also discusses the results obtained in a series of trials on blast-furnace gas.

THE reduction of the dirtiness of industrial gases to a level compatible with the smooth running of gas-cleaning plant is an important problem in the steel industry. Researches[1] are being made to assess the relative merits of existing gas-cleaning processes, to investigate new methods of cleaning, and to indicate where economies can be made.

Gas-borne dust particles, if of spherical form, range in diameter from about 0·1μ to about 1·0 mm. The particle size range in clean blast-furnace gas is 0–20μ. A complete analysis of a dust-laden sample would require information on the following:

(1) Number of particles per unit volume of atmosphere
(2) Size distribution of these particles
(3) Chemical and mineralogical composition
(4) Shape of particles.

For many investigations a knowledge of one only of these variables may be sufficient.

The instrument described in this paper was originally developed for continuous indication of the dust content in foundry atmospheres as part of a programme of research into the causes of silicosis in industry. After suitable modification it has now been applied to blast-furnace-gas dust monitoring and preliminary trials show it to be useful in this application.

METHODS OF DUST MEASUREMENT

The technique of measurement of gas contamination at present employed in industry may be described under (1) filtering methods,[2] using volatile, soluble, or paper filtering media; (2) precipitator methods[3, 4, 5]; and (3) inferential measuring techniques, such as the use of the scattering or absorption of light in the dust-laden atmosphere as a means of dust measurement.

The techniques included under (1) and (2) enable only incomplete data to be gleaned on the mechanism of gas cleaning and provide only a crude index of the efficiency of operation of a gas-cleaning plant. No warning is given of cleaning-plant breakdown until perhaps hours after it has occurred, nor is there any indication of what might well be important transient changes in dust level. Continuous indication of dust content in the gas is therefore clearly desirable.

Attention was accordingly given to more inferential methods of analysis, such as those depending on the degree of extinction or scattering of a light beam passing through a sample of the atmosphere under study.[6, 7] In the extinction method, dust-laden air intervening between a light source and a photoelectric cell acts as a variable-density filter in the light path. The dust content is estimated from the degree of obscuration of the light beam as determined by the photocell. The method is, however, relatively insensitive at low concentrations.

LIGHT SCATTERING BY SMALL PARTICLES

The method employing the scattering of light, in which the intensity of light flux scattered by the particles is taken as a measure of particle concentration, appeared to be well suited to the problem under consideration in view of its high sensitivity at low particle concentrations. This technique was therefore adopted and is considered in more detail in the following paragraphs.

The phenomenon of light scattering was noted by Tyndall[8] in 1868 and was treated theoretically by Lord Rayleigh[9] in 1871 for the particular case where the radius r of the scattering particle is small compared with the wavelength of light λ. The results, both experimental and theoretical, of later workers, notably Mie,[10] are summarized by Sinclair.[11] These results show that the scattered intensity in any direction at an angle θ to the incident light is a complicated function of the particle number concentration n, the size or size distribution for a non-homogeneous dust cloud, the refractive index of the material, the wavelength and intensity of the illumination source, the angle θ, and the distance of the point of scattering.

Since the intensity of light scattered depends on so many variables, the Tyndall beam method could

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Mr. Smith and Mr. Carlisle are on the staff of the Association.

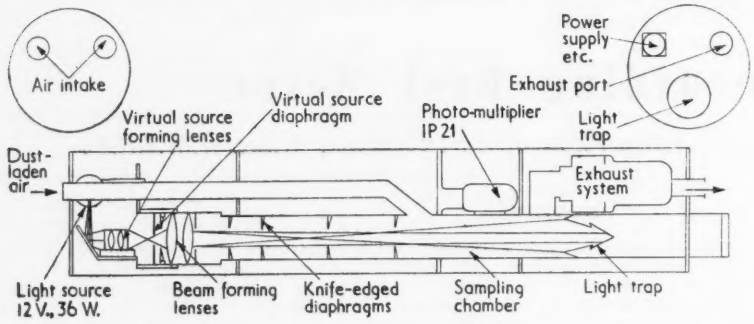

Fig. 1—Diagram of sampling unit

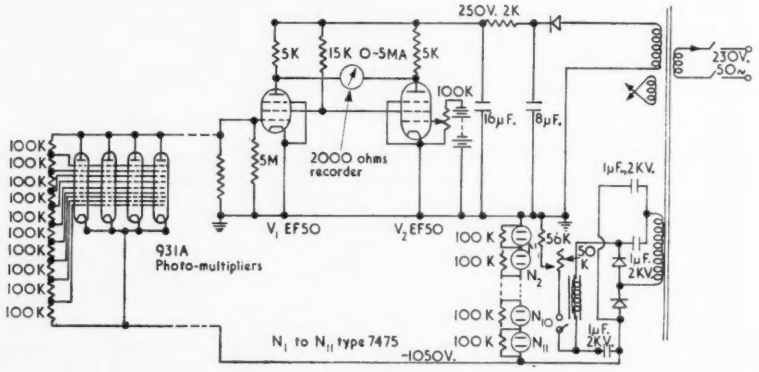

Fig. 2—Circuit details of amplifier

not be employed for absolute measurements of particle concentrations under conditions where the nature of the dust or its size distribution is variable or unknown. If these two parameters are reasonably constant the scattered light can be taken as an approximate measure of particle concentration, and the technique has the great advantage that it provides a method of continuous measurement.

DESCRIPTION AND USE OF THE INSTRUMENT

The instrument consists of two main units, a sampling tube and an electronic amplifier (Fig. 1). A lamp and lens system forms a light beam which is passed axially along a long tube terminated in a light trap. Dust-laden air passes through the same tube so that scattering occurs and the light, which is scattered approximately normally to the main beam, is measured through a suitable window by a photo-multiplier tube. The output of the photo-multiplier is displayed on a micro-ammeter or, after amplification, on a pen recorder.

A 12-V., 36-W. incandescent lamp is used as a light source, and variation of its operating condition will not only modify the illuminating beam intensity, but also its effective wavelength λ. It was therefore considered desirable to stabilize the power supply to the light source and for this purpose a constant-voltage transformer is used.

The lamp, lens, and mirror system forms a real image of the source at the diaphragm A, and a further pair of lenses combine to form an almost parallel beam, which is defined by four circular diaphragms. This beam passes through the sampling chamber and is absorbed by a light trap. Dust-laden air or gas is drawn into the sampling chamber at an angle of about 30° to the axis of the unit and is then exhausted to atmosphere. A small fan unit can be fitted to extract samples from a system at atmospheric pressure. The scattered light is viewed through a window by one or more photo-multiplier cells connected in parallel, the output from which is connected to the amplifier. The number of cells employed depends on the sensitivity required. In the instrument used for blast-furnace-gas dust monitoring three cells were used.

Figure 2 shows the circuit of the electronic unit. High voltage (1100 V.) for the photo-multipliers is

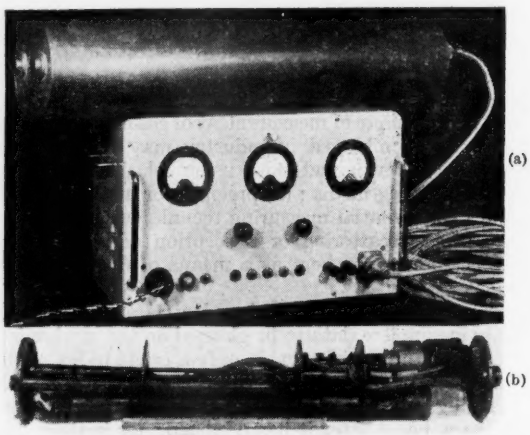

Fig. 3—(*a*) Complete instrument; (*b*) sampling unit

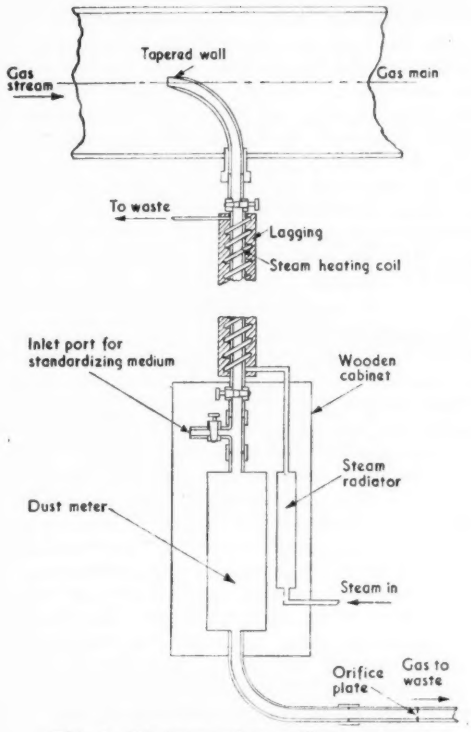

Fig. 4—Diagram of sampling system

obtained from a conventional voltage doubler circuit and a bank of neon stabilizers. The potential divider chain providing the photo-multiplier dynode potentials is mounted on the sampling unit for convenience of wiring. A 50-W. constant-voltage transformer provides 12 V. at 3 amp. to supply the lamp.

The D.C. amplifier consists of two pentodes operating as a balanced pair. A 0–5-m.amp. pen recorder is connected between their anodes. The control grid of V_2 is biased from a battery *via* a potentiometer and is adjusted initially to equalize the anode potentials of the two valves under conditions of no dust input to the sampling unit. The input voltage to the grid of V_1 is generated by the passage of the photo-multiplier current through a load resistance. Variation of this current will thus unbalance the two anode potentials, giving rise to a recorder deflection.

Meters are provided for monitoring the currents in the stabilizer bank, the photo-multiplier output, and the lamp circuit. These meters have been omitted from the simplified circuit.

The complete instrument is shown in Fig. 3*a*, and Fig. 3*b* shows the sampling unit removed from its case.

PERFORMANCE TRIALS

Trials have been carried out with the instrument to sample cleaned blast-furnace gas feeding a battery of coke ovens. The instrument was installed about 20 yards upstream from a normally used sampling point. A disused gantry running over the 5-ft. gas main gave a suitable platform for a temporary instrument cabin. The pressure in the gas main was used to pass the gas sample through the instrument and the exhaust fan was not required. The sampled gas was vented to atmosphere at a safe distance from the instrument.

Because of its relatively low concentration and small particle size, the distribution of dust in cleaned blast-furnace gas is sufficiently uniform for a representative sample to be obtained from a single point located in the centre of the main[1] (*loc. cit.*, p. 324). The conveyance of such a representative sample to the instrument requires that disturbance of the normal flow pattern in the gas main shall be small and that deposition and changes in the degree of aggregation of dust in the connecting tubing be minimized. The following provisions were therefore made :

(1) The velocity of the gas sample was made equal to that of the main gas stream by means of an orifice plate on the output side of the dust-measuring instrument
(2) A thin-walled receiver tube was used in the gas main
(3) Sharp bends in the connecting tubing were avoided. Furthermore, these connections were kept as short as possible and of as wide a bore as was compatible with a reasonable flow rate.

The sampled gas was maintained above its dewpoint by lagging and steam-heating the input pipe system to the dust meter, as shown in Fig. 4. This prevented water condensation on dust particles which can cause spurious instrument readings. Gas piping $\frac{1}{2}$ in. in dia. was used throughout the connecting system, permitting a gas sampling rate of $1\frac{1}{2}$ cu. ft./min.

The time for the dust to reach the measuring head was estimated to be about 2–3 sec.

Trial Results

Initially the zero of the instrument was checked by purging with clean filtered air. However, a sufficiently low dust content in the air could not be obtained and

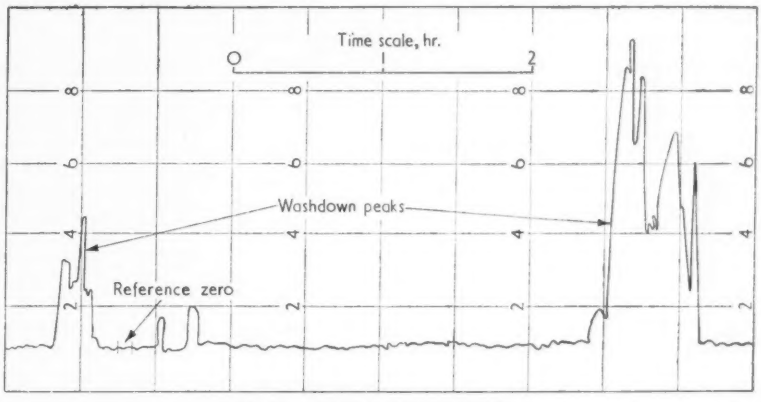

Fig. 5—Typical chart record

nitrogen from a gas cylinder was more reliable and was used subsequently in routine zero checks. These checks showed that a small zero drift in the instrument reading occurred, due to dust deposition inside the sampling chamber and on the light trap, causing spurious scattering of the main illuminating beam. This drift was overcome by cleaning out the inside of the instrument at about weekly intervals.

A typical chart section is shown in Fig. 5. The regular changes in dust level, coinciding in time with the temporary removal of part of the electrostatic cleaning plant for ' washing down,' were not previously thought to be as important as was indicated by the dust meter. Normal methods of evaluating dust content by gravimetric estimation gave no such indication. Confirmation of these large transient changes in dust content was made by taking gravimetric measurements in the usual way at the adjacent sampling point over the time that such increases were observed to occur, usually about ½ hr. Since the weight of dust collected in this time was small, an average of eight consecutive wash-down periods was taken, a similar determination being also made over the rest of the time. Of the total dust weight collected over 24 hr., some 55% was collected in the six ½-hr. wash-down periods and during these periods the mass concentration of gas-borne dust rose to over eight times that experienced during the intervening times.

No attempt was made to calibrate the instrument directly on site in terms of mass concentration of dust. This would be very difficult because of the rapid fluctuation of the dust content during the wash-down periods. However, previous experiments using an early model of the dust meter for estimation of the particle concentration in a silica dust cloud of particle size 2μ showed a consistent and linear relationship between silica particle concentration and instrument reading. Figure 6 shows the calibration curve obtained. As was suggested earlier, a reasonably consistent relationship between mass concentration and dust meter reading can be assumed provided that the nature and particle size distribution of the dust are sensibly constant. However, in blast-furnace gas it is probable that there is a considerable variation in both the chemical composition and the character of the dust from time to time, as the burden changes ; thus, inconsistency in the relationship between the instrument reading and gravimetric analyses may well be expected. A comparison was made over a period of some months between the dust meter reading integrated over a 24-hr. period and the daily gravimetric measurement. This comparison showed good qualitative agreement, but there was considerable variation in the quantitative relationship between the two measurements.

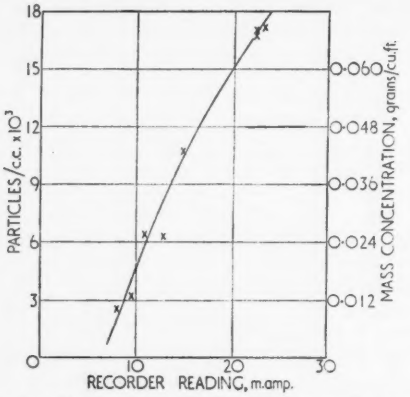

Fig. 6 — Particle-concentration / instrument-reading, using silica dust clouds of mean particle size 2μ

CONCLUSIONS

The photoelectric dust meter is capable of providing reliable and valuable information on dust concentration to supplement longer-term gravimetric analyses of blast-furnace gas. Under favourable conditions of constant particle size and nature of dust, the instrument can be calibrated to give quantitative values of dust content. Measurements on cleaned blast-furnace gas show that the instrument reading gives reasonable qualitative agreement with gravimetric analyses but that a direct calibration in terms of mass concentration cannot be given in this particular application. This discrepancy can probably be explained by variation in the nature of the dust in the gas. The instrument is of particular value in that it responds rapidly to any sudden changes in dust concentration and may be readily adopted to operate an alarm system. The presentation of a continuous record of dust-content variation as a function of time can be a valuable aid in tracing the cause of excessive gas contamination in a plant.

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Cooling of Rimming Steel Ingots in a Casting Pit

By R. T. Fowler, B.Sc., Ph.D., A.R.I.C., A.I.M.,
and L. H. W. Savage, M.Sc., F.R.I.C., M.Inst.F.

SYNOPSIS

Further observations have been made on the temperature distribution at mid-height of an 8-ton slabbing ingot mould between teeming and stripping, using an improved technique to eliminate possible errors and obtain fuller data. The heat lost by the steel from a horizontal slice of the ingot at mid-height has been calculated for nine casts of low-carbon rimming steel teemed in a casting pit. These results have a standard deviation of about 5% of the mean value, probably owing to differences in the times from tap to teem, in the initial temperatures of steel and mould, and in the rate of heat loss from the surface of the mould.

A good correlation has been established between the change of temperature of a single mould surface reference point and the change in heat content of steel and mould, and this will facilitate fuller investigations on all the ingot moulds during a single cast.

It was found that one minute after the end of teeming all superheat had been lost from the steel, and it has been estimated that there could then be a mean shell thickness of 1¼ in. and that heat transfer between steel and mould could be entirely by radiation.

By making a number of simplifying assumptions, estimates have been made of the rate of solidification of the mid-height slice of steel and of the temperatures at its surface and centre.

Lack of knowledge of the temperature distribution and heat contents of steel ingots between teeming and rolling results in empirical rules stipulating minimum times of standing between teeming and stripping, and similar data, which vary according to practice at different works. They ensure, as far as possible, that the ingots will not deform or bleed when stripped and will be at a sufficiently uniform temperature to roll without difficulty. The temperature distribution and heat content of the individual ingots of a single cast may, however, differ to some extent. Further differences are also to be expected between ingots from different casts.

An empirical rule defining the time between teem and strip will thus tend to suit the ingot that cools at the slowest rate. On the other hand, an empirical soaking time will tend to suit the ingot that has cooled most during the track time.

It is therefore desirable to determine by experiment what differences can occur between the individual ingots in any particular practice, so as to ascertain what saving in time and fuel is possible. Saving of time has the effect of increasing the pit availability,[1] and therefore can reduce the number of soaking pits required to supply the rolling mill, and so reduce the fuel requirements still further.

Data are required on many ingots, under conditions to be expected in practice, before any conclusions can be drawn as to the magnitude of the differences that occur; it is impracticable, however, to determine these by direct measurement of the steel temperature at a number of points within the ingots. Thermocouples can be fixed, without interference to normal practice, to a number of points on an ingot mould,[2, 3] which thus becomes a calorimeter to measure the heat lost by the steel up to the time of stripping. The temperature distribution in the steel can also be calculated, but with less accuracy, because of inadequate data on the latent heat of fusion of the steel and on the effective emissivity between the steel and the mould.

Further improvements have now been made to this technique, by the use of thermocouple assemblies passing through the mould wall, to obtain fuller information on the form of the temperature contours, particularly near the inner surface. Nevertheless, 40 thermocouples are required on a single plane at the mid-height of an 8-ton slabbing ingot mould, so that it would be difficult to carry out such comprehensive measurements simultaneously on two or more moulds in the same cast. Tests have therefore been carried out on successive casts, using a single mould placed in different positions in a casting pit.

The main purpose of these tests was to ascertain the magnitude of the differences in heat contents of the ingots, and also to establish whether the change in heat content with time could be directly correlated with the change of temperature with time of a single reference point on the outer mould surface. A satisfactory correlation would make it possible to study simultaneously all the ingots in a single cast, to ascertain whether appreciable differences existed between them and, if so, whether one particular ingot could be used to characterize the whole cast.

EXPERIMENTAL TECHNIQUE

Ten ½-in. dia. holes were drilled through the mould wall on the mid-height plane in the positions shown in Fig. 1, so that they were approximately equi-spaced but, with the exception of the corners, corresponded with the top of a corrugation of the inside face. The first inch of each hole was tapped ⅝ in., to allow the thermocouple plugs to be screwed into position.

The thermocouple plugs (Fig. 2) were constructed from cast iron of the same composition as the mould, the lengths being varied with the thickness of the mould wall so that the ends were flush with the inner

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Dr. Fowler and Mr. Savage are in the Plant Engineering Division of the Research Association.

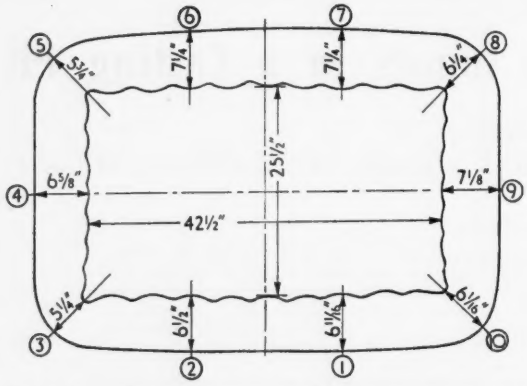


Fig. 1—Location of thermocouple plugs on horizontal mid-height section of test mould. (Mould height: 6 ft. 0 in.; mould weight: 8·8 tons; ingot weight (nominal): 8·0 tons)

and outer faces. Chromel and alumel wires (22 S.W.G.) were inserted in the four holes drilled through each plug, the hot junction of the thermocouples being formed on the centre-line of each plug. The leads, insulated with silicone-impregnated glass fibre sleeving, were secured in longitudinal slots at the sides of the plugs. This arrangement resulted in even less interference to the normal heat flow than that previously used,[3] whilst the use of cast iron instead of mild steel ensured that the temperature gradients at the points of measurement would not be affected by material of different thermal conductivity.

The thermocouple wires from each side of one of the mould diagonals were insulated with glass fibre sleeving and bound with asbestos tape into two cables about 8 ft. long, which were firmly secured by wire to ½-in. bolts screwed into the mould in such a way that there was no strain on the wires leaving the thermocouple plugs.

The connections to the temperature recorder were made by multi-pin plugs to an 80-ft. cable. This alteration of the previous arrangement made it possible to transfer the junctions to a cooler zone at the side of the casting pit, whilst the compact junction boxes ensured that any temperature correction would be identical for every thermocouple.

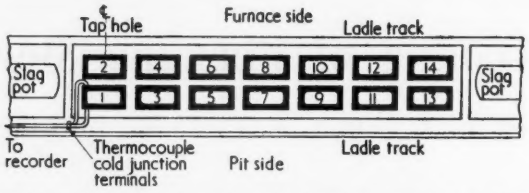


Fig. 3—Diagram of casting pit showing mould positions

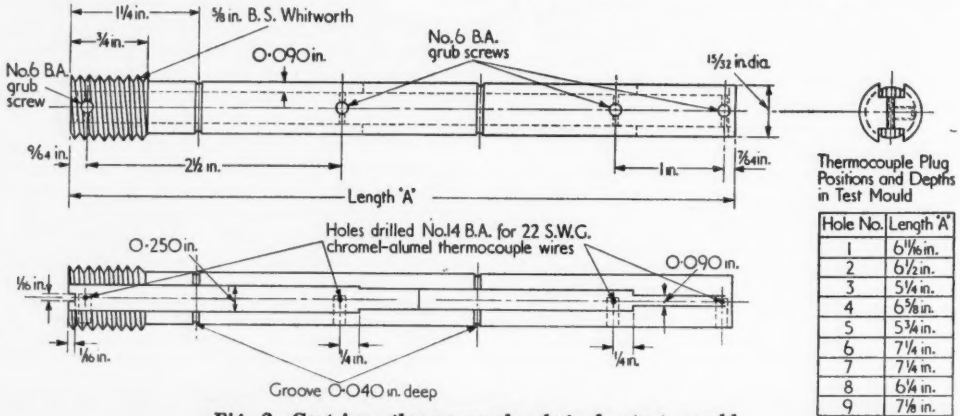
All the temperatures were recorded on a single 12-point recorder, using a multipoint switchbox and a marker technique[4] that facilitated ready identification of the individual thermocouples. The full cycle of 40 mould thermocouples, 4 junction thermocouples, and 4 markers was completed in about 50 sec.

In the plant where the experiments were conducted, rimming steel is top teemed into moulds set in pairs in a casting pit (*see* Fig. 3), from a ladle held in a ladle carriage. After setting the test mould in position the 80-ft. connecting cable was laid between the ladle track and the casting pit, the multi-pin plug and socket junction boxes being placed at the top of the wall and further protected with asbestos cloth. Thin steel sheets were placed to bridge the top of the test mould and the adjacent moulds, to reduce the risk of damage to the thermocouples from liquid steel splashes during teeming, but the sheets were removed as soon as the rimming action ceased and the ingots had been 'plated.' The junctions were disconnected immediately before stripping but were remade as soon as the mould had been set on the bank, so as to take observations of the rate of cooling of the mould and to check the thermocouple circuits.

The temperature of the liquid steel was determined, by means of a dip thermocouple, in the bath of the furnace immediately before tapping, and then at the top of the teemed test mould as soon as the ladle carriage had been moved away.

METHOD OF CALCULATING HEAT LOSS

After the completion of each test run, the temperature gradients along each of the thermocouple plugs were plotted at intervals of 10 min. from the time of start of teeming the test mould. From these gradients, a typical set of which is shown in Fig. 4, the isotherms



Hole No.	Length 'A'
1	6 1/16 in.
2	6½ in.
3	5¼ in.
4	6⅝ in.
5	5¾ in.
6	7¼ in.
7	7¼ in.
8	6¼ in.
9	7⅛ in.
10	6 1/16 in.

Fig. 2—Cast-iron thermocouple plugs for test mould

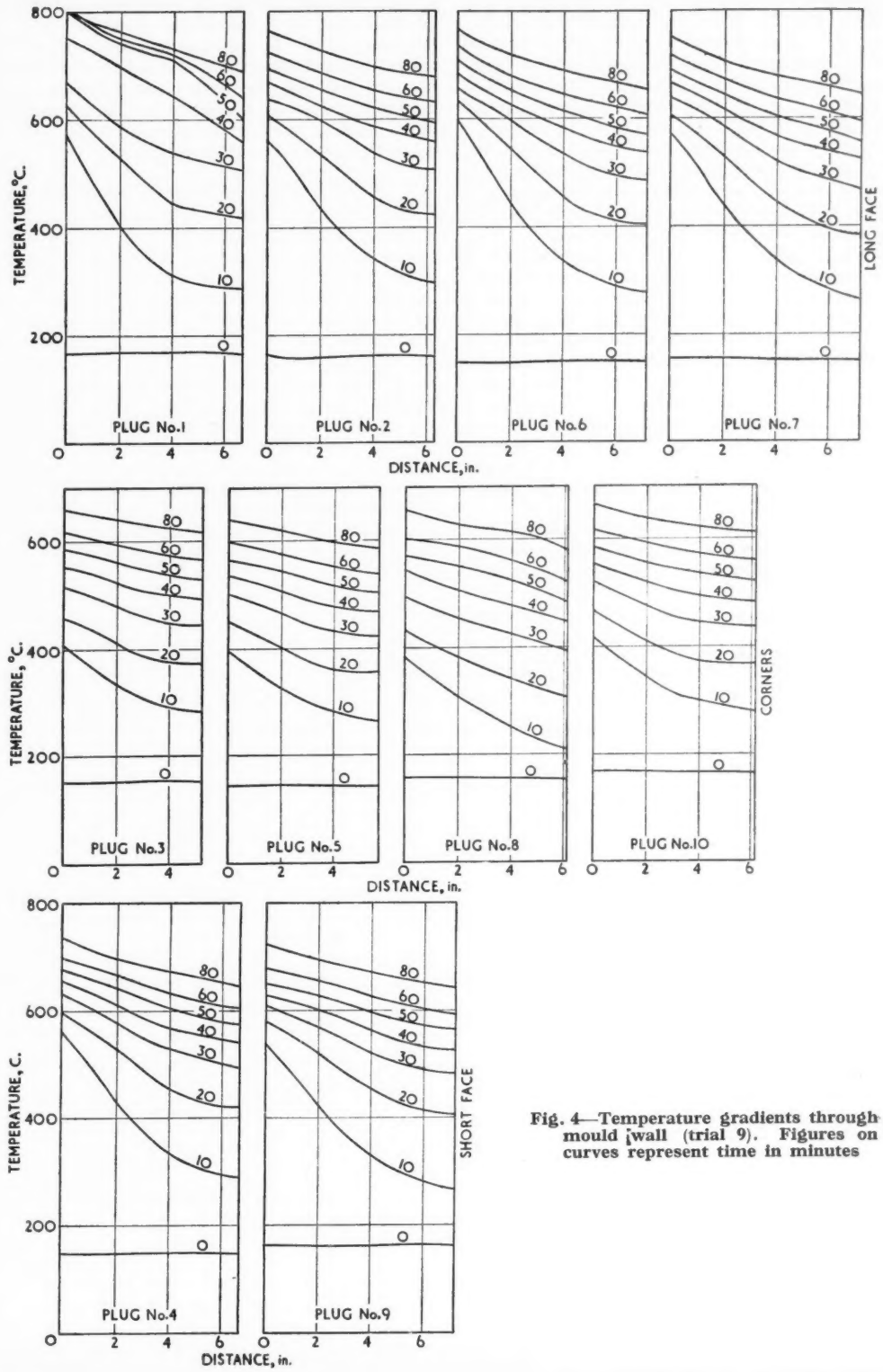


Fig. 4—Temperature gradients through mould wall (trial 9). Figures on curves represent time in minutes

in the mid-height horizontal slice of the mould were plotted (*see* Fig. 5). The heat content of the corresponding slice of unit thickness at each time interval was then determined from the planimetered areas between isotherms and the appropriate heat content of the iron at the mean temperature. The calculations for the original of Fig. 5 are also given in Table I.

The average surface temperature at each time was also determined, to estimate the heat lost from the mid-height slice of the mould by convection and by radiation, the latter varying according to the number of hot moulds surrounding the test mould.

Assuming negligible heat transfer perpendicular to the mid-height plane, the total heat lost by the mid-height slice of the steel was thus equal to the increase in heat content of the corresponding slice of the mould, plus the cumulative heat loss from the surface by radiation and convection. The heat loss per unit weight of steel was obtained using a mean density based on the overall weights and measurements of a number of test ingots, and finally the heat content of the steel was obtained by subtracting the heat loss from the initial heat content, assuming in all cases a temperature drop of 30° C. in the ladle, between the furnace and the test mould.

All isotherms were plotted at 10-min. intervals from the start of teeming the test mould up to 60 min., and also at 80 and 100 min. when appropriate. A shorter method, using the averaged thermocouple readings and the appropriate areas between them (bottom of Table I), gave results agreeing closely with those obtained from the isotherms; this method was used to estimate the heat content during the first five minutes when the temperature gradients were steep, and at certain times greater than 100 min. when the gradients were very gradual.

PROCEDURE AND RESULTS OF TEST RUNS

Nine runs were made with the test mould in this series of experiments, the first run being with a cold isolated mould in a cold pit and the subsequent runs being on eight consecutive casts with the test mould in various positions in the pit. For convenience, most of these runs were made with the test mould on the casting-bay side of the pit, duplicate runs being made in positions 3, 5, and 7 (*see* Fig. 3), and a single run in position 1, where one short face was adjacent to the hot slag pot and was also subjected to splashing by slag during the running-out of the furnace. The last run was made on the furnace side of the pit in position 6, to see whether differences resulting from orientation of the mould could be detected.

A summary of mould positions, proximity of hot moulds, times from tap to teem and from teem to strip, and liquid steel temperatures, is given in Table II.

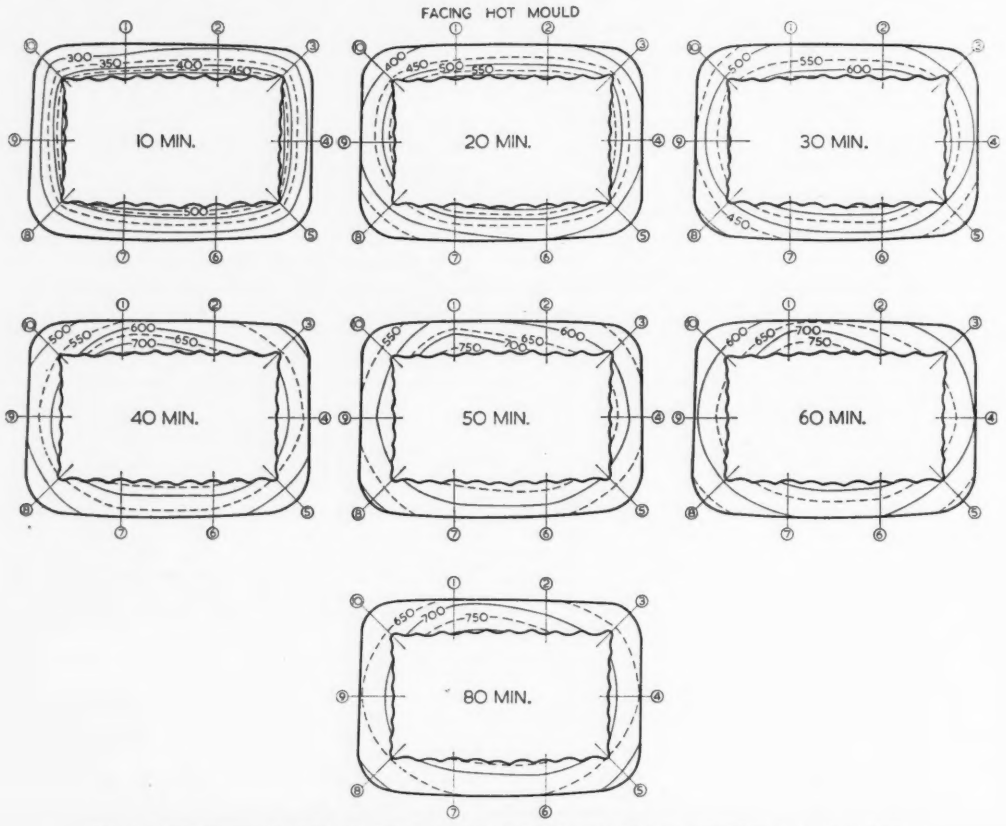


Fig. 5—Isotherms in wall of ingot mould (trial 9). Mould in position 5 (⅛ full size)

Table I

Table I

CALCULATION OF HEAT CONTENT OF MOULD* AND HEAT LOSS FROM STEEL (TRIAL 9)

Isotherms, °C.	Average Heat Content *H*, cal./g.	Time From Start of Teem, min. 10: Area *A*,† sq. cm.	10: Total Heat,‡ kg.cal.	20: Area *A*, sq. cm.	20: Total Heat, kg.cal.	30: Area *A*, sq. cm.	30: Total Heat, kg.cal.	40: Area *A*, sq. cm.	40: Total Heat, kg.cal.	50: Area *A*, sq. cm.	50: Total Heat, kg.cal.	60: Area *A*, sq. cm.	60: Total Heat, kg.cal.	80: Area *A*, sq. cm.	80: Total Heat, kg.cal.
250–300	35·5	32·4	518·0												
300–350	42·5	28·9	553·2	2·2	42·1										
350–400	49·5	16·4	365·6	19·9	443·6	0·5	11·1								
400–450	57·0	9·7	294·0	38·9	998·6	12·1	310·6								
450–500	64·5	8·1	235·3	18·8	546·1	27·3	793·1	10·9	316·6	0·7	20·3				
500–550	72·9	7·2	236·4	12·2	594·6	36·5	1984·4	32·9	1080·2	14·1	462·9	2·6	85·4		
550–600	81·5			8·5	312·0	16·2	594·6	36·5	1222·3	41·8	1534·3	26·0	954·3	2·4	88·1
600–650	90·7			2·0	81·7	9·2	375·8	16·4	669·9	30·3	1237·7	43·0	1756·5	29·9	1221·4
650–700	100·3					0·8	36·1	5·9	266·5	9·6	433·6	20·5	926·0	45·0	2032·7
700–750	117·5							3·1	164·0	3·9	206·4	7·3	386·3	19·0	1005·4
750–800	128·5									2·1	121·5	3·2	185·2	5·4	1016·2
800–850	136·3													0·8	49·1
Total heat in mid-height slice of mould			**2157·5**		**2824·7**		**3319·7**		**3719·6**		**4016·8**		**4293·7**		**4709·3**
Initial heat in mid-height slice of mould (155° C.)			**906·6**		**906·6**		**906·6**		**906·6**		**906·6**		**906·6**		**906·6**
Heat lost by radiation and convection from surface of mid-height slice§			**8·9**		**33·0**		**69·5**		**116·0**		**169·5**		**231·0**		**375·0**
Total heat lost by mid-height slice of steel			**1259·8**		**1951·1**		**2482·7**		**2929·0**		**3279·7**		**3618·1**		**4177·7**
Heat lost by steel, cal./g.‖			**26·57**		**41·15**		**52·36**		**61·79**		**69·18**		**76·32**		**88·12**
Heat gained by mould, cal./g. of steel			**26·39**		**40·47**		**50·91**		**59·36**		**65·63**		**71·47**		**80·24**
Heat lost from surface, cal./g. of steel			**0·18**		**0·68**		**1·48**		**2·43**		**3·55**		**4·85**		**7·88**

SHORTENED METHOD USING AVERAGED TEMPERATURES OF ZONES ENCLOSED BETWEEN BANKS OF THERMOCOUPLES

Zone Between Thermocouple Banks	Weight of 1-cm. thick Slice, g.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.	Average Temp., °C.	*H*, cal./g.	Total Heat, kg.cal.
1st and 2nd	5975	464	62·6	374·0	523	72·4	432·6	572	80·8	482·8	611	88·0	525·8	638	93·1	555·6	668	99·0	591·5	704	106·0	633·4
2nd and 3rd	22,257	375	49·5	1101·7	462	62·4	1388·8	537	75·0	1669·0	575	81·5	1813·9	611	88·0	1958·6	640	93·6	2038·2	679	101·0	2248·0
3rd and 4th	18,517	294	38·2	707·3	402	53·3	987·0	480	65·4	1211·0	532	74·1	1372·1	571	80·8	1496·2	600	86·0	1592·5	650	95·6	1770·2
Total heat in mid-height slice of mould				**2183·0**			**2808·4**			**3363·1**			**3711·8**			**4010·4**			**4267·2**			**4651·6**

* Thermal properties of mould iron taken from data by Hatfield[5]
† Planimetered area between isotherms on original of Fig. 5
‡ Heat content of 1-cm. thick slice of area *A* = area × scale factor × 7·037 (density of mould iron) × *H*
§ Radiation on one side only, because of other hot moulds
‖ Total weight of 1-cm. thick slice of steel = 48·3 kg. (density of steel = 6·67 g./c.c.; density variation with temperature is ignored)

Table II
SUMMARY OF TEST CONDITIONS

Trial No.*	Cast No.	Date and Time of Tap	Time From Tap to Teem, min.	Time From Teem to Strip, min.	Temp. of Test Mould Before Teem, °C.	Steel Temp., °C.		Position of Test Mould in Pit†	Plug Nos. Facing Pit Wall‡	Remarks
						Furnace	Mould			
7	L.693	7.1.51 9.30 p.m.	17	214	20	1592	1525	12	6 and 7	Cold pit (Sunday night tap). Long stripping time, owing to faulty crane
8	L.695	8.1.51 7.40 p.m.	20½	126	80	1580	1518	7	6 and 7	Moulds 5, 6, and 8 full; mould 9 empty; mould 10 three-quarters full
9	L.696	9.1.51 7.40 a.m.	14	94	155	1580	1529	5	6 and 7	Surrounding moulds full
10	L.697	9.1.51 9.00 p.m.	9	96	105	1608	1530	3	6 and 7	Surrounding moulds full
11	L.698	10.1.51 8.20 a.m.	8	102	150	1600	1533	3	6 and 7	Surrounding moulds full
12	L.699	10.1.51 6.17 p.m.	14½	74	190	1592	1523	5	6 and 7	Surrounding moulds full
13	L.700	11.1.51 3.45 a.m.	17	177	165	1584	...	7	6 and 7	Moulds 5, 6, and 8 full; moulds 9 and 10 empty
14	L.701	11.1.51 2.50 p.m.	7½	118	225	1590	1531	1	1 and 2	Surrounding moulds full
15	L.702	12.1.51 1.25 a.m.	10	146	170	1587	1552	6	1 and 2	Surrounding moulds full. Test mould held a slagged ingot, and 'blew.' Troublesome to strip

* Trials 1–6 have been previously reported[2,3] † *See* Fig. 3 ‡ *See* Fig. 1

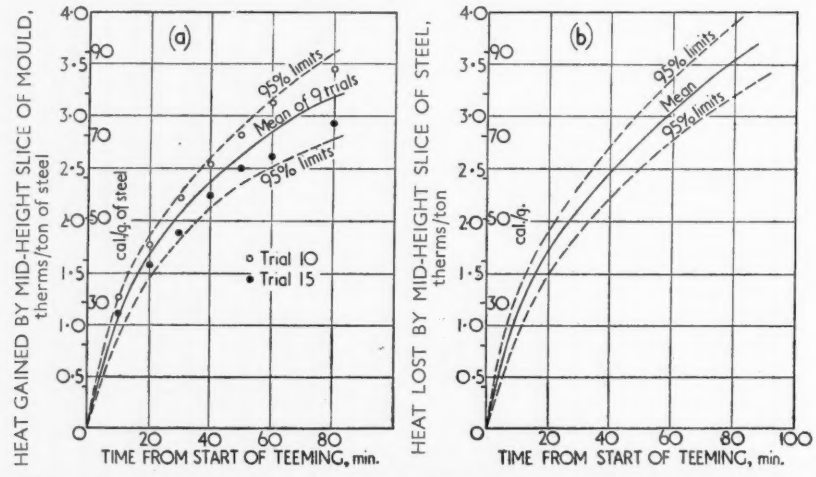


Fig. 6—Heat gained and lost *vs.* time: (*a*) Heat gained by horizontal mid-height slice of mould; (*b*) heat lost by horizontal mid-height slice of steel

Table III

HEAT GAINED BY MID-HEIGHT SLICE OF MOULD

Figures given in cal./g. of steel

Time From Start of Teem, min.	Trial No.									Average Heat Gained By Mould	Standard Deviation
	7	8	9	10	11	12	13	14	15		
10	30·2	25·9	26·4	31·5	28·2	24·6	26·2	25·4	27·7	27·3	2·23
20	42·8	40·5	40·5	43·9	44·4	39·2	38·8	41·9	39·4	41·2	2·04
30	52·7	50·1	50·9	55·0	54·3	49·2	47·9	49·0	47·0	50·6	2·80
40	60·3	58·8	59·4	63·1	62·3	56·2	55·7	57·1	55·8	58·9	2·73
50	66·9	65·5	65·6	70·1	68·0	62·9	62·0	63·8	62·0	65·3	2·73
60	71·9	70·8	71·5	77·9	74·5	68·3	66·8	69·0	64·9	70·7	3·96
80	77·5	80·1	80·2	85·4	84·6	...	72·2	78·8	72·2	79·0	4·56
100	83·8	...	...	...	...	...	81·1	...	...	...	...

Table IV

HEAT LOST BY MID-HEIGHT SLICE OF STEEL

Figures given in cal./g.

Time From Start of Teem, min.	Trial No.									Average Heat Lost By Steel	Standard Deviation
	7	8	9	10	11	12	13	14	15		
10	30·3	26·0	26·6	31·6	28·4	24·7	26·3	25·5	27·8	27·4	2·28
20	43·5	41·1	41·2	44·5	45·0	39·9	39·6	42·6	40·1	41·9	2·04
30	54·4	51·5	52·9	56·4	55·7	50·8	49·6	50·7	48·4	52·3	2·66
40	63·5	61·2	61·8	65·3	64·7	58·8	58·8	59·8	58·1	61·4	2·66
50	71·9	69·2	69·2	73·5	71·6	66·7	66·7	67·9	65·4	69·1	2·73
60	79·3	76·0	76·3	80·9	79·5	73·5	73·3	74·5	69·5	75·9	3·63
80	91·5	89·1	88·1	91·4	92·8	...	84·9	87·6	79·6	88·1	4·64
100	103·1	...	...	...	...	...	96·4	...	...	...	...

The recorder was started when the steel hit the bottom plate of the test mould, this being taken as zero time; the steel reached the mid-height slice of the mould, where the thermocouples were located, after 1–1½ min. The recorder was then run continuously until the usual time for stripping. When this operation was delayed by crane breakdown or by bunching of furnaces, the recorder was subsequently run intermittently, to observe the very gradual changes in temperature.

The heat gained by the mid-height slice of mould and the estimated heat loss from the steel are given in Tables III and IV for all nine casts, and the results are plotted in Fig. 6. The heat content of the steel is given in Table V.

Table V

HEAT CONTENT OF STEEL

Figures given in cal./g.

Heat Content of Steel	Trial No.									Average Heat Content	Standard Deviation
	7	8	9	10	11	12	13	14	15		
At start of tap into ladle	316·6	314·8	314·8	319·2	318·0	316·6	315·4	316·2	315·8	316·4	1·46
At start of teem into mould*	311·6	309·8	309·8	314·2	313·0	311·6	310·4	311·2	310·8	311·4	1·46
In mould:											
Time from start of teem, min.: 10	281·3	283·8	283·2	282·6	284·6	286·9	284·1	285·7	283·0	284·0	2·17
20	268·1	268·7	268·6	269·7	268·0	271·7	270·8	268·6	170·7	269·5	1·34
30	257·2	258·3	256·9	257·8	257·3	260·8	260·8	260·5	262·4	259·1	1·32
40	248·1	248·6	248·0	248·9	248·3	252·8	251·6	251·4	252·7	250·0	2·04
50	239·7	240·6	240·6	240·7	241·4	244·9	243·7	243·3	245·4	242·3	2·10
60	232·3	233·8	233·5	233·3	233·5	238·1	237·1	236·7	241·3	235·3	2·96
80	220·1	220·7	221·7	222·8	220·2	...	225·5	223·6	231·2	223·5	3·72
100	208·5	...	...	...	...	...	214·0	...	...	...	...

* The steel in the ladle is assumed to be 30° C. below furnace temperature

DISCUSSION

Experimental Technique

The modifications made to the thermocouple system proved entirely satisfactory. The glass fibre and asbestos tape insulation were embrittled by the rigorous conditions imposed, including rapid temperature changes and coating with liquid slag, but only one set of thermocouples failed owing to short circuits, and then only during the last run. For the first eight runs the thermocouple junction boxes at the pit side did not attain a temperature of more than 70° C., and no temperature correction was necessary. In the last run, however, the temperature rose to 180° C., and corrections up to 15° C. had to be applied.

Samples taken for analysis during the drilling of the holes in the mould wall (*see* Table VI) show that the mould was homogeneous in chemical composition ; no data were obtained on physical homogeneity.

Heat and Temperature Changes of Mould and Steel

The results in Tables II and III show that, although good agreement was obtained between each pair of duplicate runs, there is an appreciable scatter both in the heat gained by the mid-height slice of the mould and in the estimated heat lost by the corresponding slice of the steel. Whilst the data were inadequate for statistical analysis, the results suggest that the heat loss from the steel in the mould increases with :

(i) Increase in initial steel temperature in the furnace
(ii) Decrease in time from tap to start of teem of test mould
(iii) Decrease in initial temperature of test mould
(iv) Decrease in mean temperature of surroundings (varying with pit position and number of hot moulds around)
(v) Increase in thickness of ladle lining.

Empirical stripping times will probably be based, after trial and error, on those ingots whose heat losses are below the average ; similarly, empirical soaking times will tend to suit the ingots whose heat losses up to the time of stripping are above the average. Attempts should therefore be made to ascertain whether the heat loss can be correlated more precisely with these uncontrolled initial conditions, and thus whether the stripping and heating times should be reduced in some instances.

In all cases the temperatures in the mould wall facing another hot mould were considerably higher than those in the wall facing the casting-pit wall (*see* Figs. 4 and 5) ; much smaller differences were found between the temperatures of the short faces of the mould, irrespective of whether they faced a hot or cold mould. During trial 14, when one short face was adjacent to the hot slag pot, a small rise in temperature was observed before and immediately after the start of teeming, but after 5 min. there were no temperature differences between the short face and the opposite side.

At the start of teeming the mould was always at a substantially uniform temperature, but the average value differed appreciably between runs, owing to differences in the time that had elapsed since stripping the previous cast. The test mould had been set between casts in an isolated and more exposed position than the remainder of the moulds, and was probably at a slightly lower temperature.

Table VI

ANALYSES OF CAST IRON TAKEN FROM THERMOCOUPLE HOLES IN TEST MOULD*

Sample	Si, %	S, %	P, %	Mn, %	Total Carbon, %
Hole 1 Inside	1·43	0·056	0·089	0·88	3·16
Outside	1·48	0·056	0·088	0·90	3·16
Hole 2 Inside	1·43	0·060	0·084	0·90	3·22
Outside	1·43	0·058	0·090	0·89	3·35
Hole 3 Inside	1·41	0·062	0·084	0·85	3·20
Outside	1·38	0·062	0·090	0·85	3·38
Hole 4 Inside	1·41	0·062	0·088	0·87	3·30
Outside	1·38	0·056	0·093	0·88	3·38
Hole 5 Inside	1·43	0·054	0·084	0·82	3·23
Outside	1·41	0·054	0·090	0·83	3·35
Hole 6 Inside	1·41	0·058	0·089	0·83	3·22
Outside	1·38	0·062	0·089	0·82	3·36
Hole 7 Inside	1·40	0·058	0·093	0·83	3·12
Outside	1·43	0·070	0·092	0·82	3·29
Hole 8 Inside	1·43	0·056	0·088	0·80	3·16
Outside	1·40	0·056	0·094	0·81	3·30
Hole 9 Inside	1·38	0·060	0·092	0·83	3·10
Outside	1·43	0·062	0·088	0·85	3·23
Hole 10 Inside	1·43	0·056	0·091	0·84	3·30
Outside	1·43	0·056	0·088	0·84	3·26

* See Fig. 1

For the type of mould and practice studied, there is a good correlation between the temperature rise of an outer surface reference point and the average surface temperature rise, the heat gained by the mid-height slice of mould, and the heat lost by the corresponding mid-height slice of steel for the period 4–100 min. from the start of teem. This correlation is shown in Fig. 7, in which the reference point is the midpoint of the long face adjacent to the wall of the casting pit. It is thus possible to use the reference point to ascertain with reasonable accuracy the differences between all the ingots of a single cast, without the necessity for a thorough investigation of the temperatures of the mould wall in every instance. When further results are obtained it may be possible to establish better correlations, according to mould position and proximity to other hot moulds.

In the two cases where stripping was unduly delayed, the inner face temperatures of the mould reached a maximum 2 hr. after the start of teeming, and during the next hour fell gradually by 10° C. The outside surface temperatures reached their maxima about 20 min. later than the inner face, and were then substantially constant. This indicates that heat is being removed from the core of the ingot with little change in the temperature of the shell.

During one run (trial 15) the temperature measurements during the first 5 min. from start of teem were limited to the inner mould face thermocouples. Some results are plotted in Fig. 8, and show a very slight rise

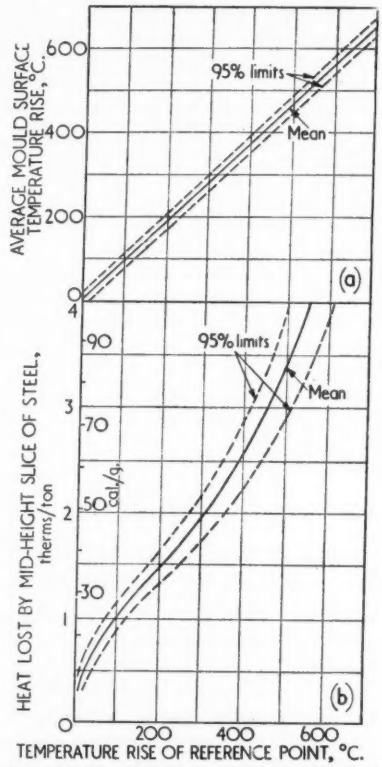


Fig. 7—Correlation between surface reference point and : (*a*) average surface temperature of mould ; (*b*) heat lost by mid-height slice of steel

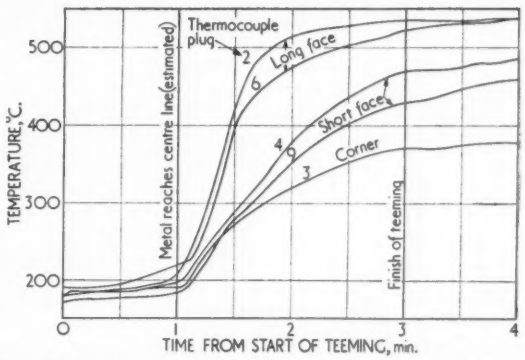


Fig. 8—Inner mould face thermocouple temperatures from start of teem (trial 15)

in temperature before the steel reaches the centre-line (owing to conduction up the mould and direct radiation from the metal stream), followed by steep rises over periods of ½ min. to 2 min., depending on the thermocouple position, and then a gradual increase. In no case was any initial peak temperature, reported by some observers, observed. The temperatures at the corners are much lower than those of any face.

The temperatures of the steel near the top of the test mould, as determined by dip thermocouples 4 min. after start of teeming (1 min. after end of teeming), were about 1530° C. in nearly all cases. Since this has been estimated to be the approximate melting point of the low-carbon rimming steel cast, all the superheat initially in the steel must have been removed almost instantaneously. The total heat loss at this time is then equivalent to the solidification of 12% of the steel ; this corresponds to an average shell thickness of 1¼ in., assuming that the latent heat of fusion is 65 cal./g., that the solid steel is also at 1530° C., and that there is a temperature drop of 30° C. between the furnace and the mould, owing to cooling in the ladle.

Heat Transfer from Steel to Mould

The net heat flow from steel to mould has been calculated, over each time interval, from the incremental heat losses, and is shown as the lower curve

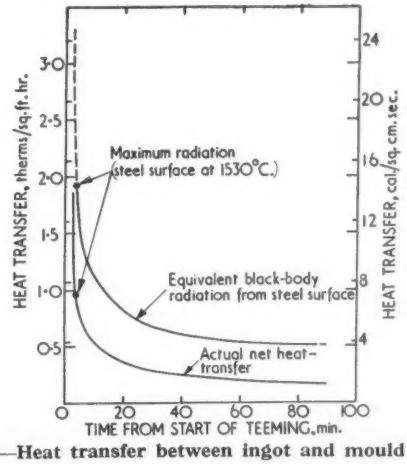


Fig. 9—Heat transfer between ingot and mould

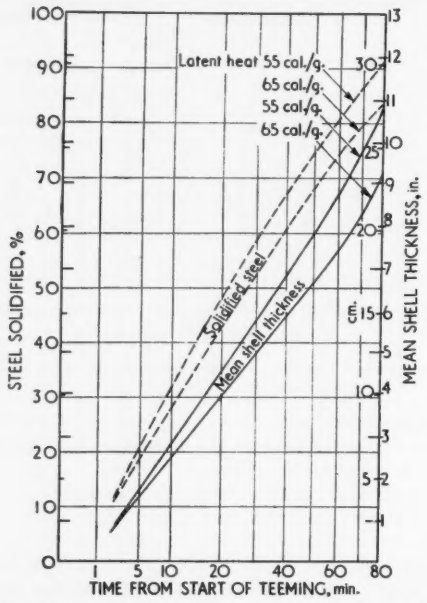

Latent heat 55 cal./g.
65 cal./g.
55 cal./g.
65 cal./g.
Solidified steel
Mean shell thickness
STEEL SOLIDIFIED, %
MEAN SHELL THICKNESS, in.
TIME FROM START OF TEEMING, min.
1 5 10 20 40 60 80
0 10 20 30 40 50 60 70 80 90 100
1 2 3 4 5 6 7 8 9 10 11 12 13

Fig. 10—Mean shell thickness and percentage of steel solidified, *vs.* time from start of teem. (Mean of all trials)

in Fig. 9. From the measured mould surface temperature and assuming an effective emissivity of 0·5 (based on an emissivity of 0·53 for unoxidized steel and 0·9 for oxidized cast iron), the gross heat flux from the steel surface has been calculated and is shown as the upper curve in Fig. 9. The flux at 4 min. from start of teeming is 14·4 cal./sq.cm. sec., corresponding to a black-body temperature of 1530° C., which is the same as that measured by the dip thermocouples at this time. This suggests that subsequent heat transfer can be entirely by radiation, and a 'gap' may already have formed. Before this time the heat transfer is greater than that obtainable by radiation alone, and some conduction must occur.

Rate of Solidification of Steel

By making further simplifying assumptions, estimates have been made of the proportion of the mid-height slice of the ingot which has solidified and of the temperature of the middle of this slice after complete solidification. Details of the assumptions and the method of calculation are given in the Appendix, and the results are shown in Fig. 10.

Significance of Heat Content and Temperature Changes

The overall changes in the heat content and temperatures of steel and mould from time of tap to time of strip are summarized in Fig. 11. Even while still in the mould, the centre temperature of the ingot falls rapidly as soon as it is completely solid. It follows that a delay of, for example, 20 min., which would apparently entail a relatively small heat loss of $\frac{1}{4}$ therm/ton, could bring the centre temperature below rolling temperature. This could only be restored by the conduction of heat through the body of the steel, and would result in increased time in the soaking pits, with a resultant increase in fuel consumption and decrease in pit availability.

CONCLUSIONS

The following conclusions have been derived from observations on the cooling of low-carbon rimming steel in an 8-ton slabbing ingot mould in a casting pit, and may not be applicable to other practice. The results refer to a horizontal slice at mid-height of the ingot, and assume negligible heat transfer to the top or bottom.

(1) The rate of heat loss from the mid-height slice of a solidifying steel ingot varies appreciably, the standard deviation of nine casts studied being approximately 5% of the mean value. There is a suggestion that this occurs because the rate of heat loss increases with

(*a*) Increase in initial steel temperatures in the furnace
(*b*) Decrease in time from tap to teem of the individual moulds
(*c*) Decrease in initial mould temperature at start of teem
(*d*) Decrease in average temperature of surroundings
(*e*) Increase in thickness of ladle lining,

but the present data are inadequate to separate or assess these factors.

(2) There is good correlation between the rise in temperature of a mould surface reference point and the average surface temperature rise, the increase in heat content of the mould, and the heat loss from the steel.

(3) The technique using 40 thermocouples in a single mould cannot readily be extended to more than one mould in a cast, but using this correlation a single thermocouple (or contact pyrometer) at the reference point will enable all the ingots to be studied simultaneously, to establish differences between them.

(4) All superheat is removed from the steel in 4 min. from the start of teeming (*i.e.*, by 1 min. after the end of teeming), and at that time there may be $1\frac{1}{4}$ in. thickness of solid crust.

(5) It is possible for heat transfer to be entirely by radiation after 4 min. from start of teem, indicating the formation of a 'gap' between mould and ingot.

(6) By making a number of simplifying assumptions it has been estimated that, on the average, the mid-height slice of the ingot will be 85% solid after 80 min. and completely solid after 160 min.

(7) After the steel has solidified, the centre temperature falls rapidly with only a slight fall in the surface temperature.

APPENDIX

Approximate Estimate of the Rate of Solidification and the Temperature of the Steel

The temperatures close to the inner face of the ingot mould, and the heat flux from steel to mould, have been experimentally determined, and it is therefore possible to calculate by step methods the state of the steel, assuming values for the surface emissivities. Such step methods are laborious when extended to heat flow in two dimensions, and for the purposes of this paper a rather crude but simpler method has been used to estimate the solidification rate and

the temperature of the steel, both at the surface and at the centre, after complete solidification.

It has been assumed that the cross-section of the ingot approximates to a rectangle, and that the curved isotherms which actually occur can be replaced by a series of rectangles, the outermost conforming to the outside of the ingot at a temperature equal to the average steel surface temperature. It has further been assumed that the temperature distribution along the axes is parabolic (*see* Fig. 12), and that the specific heat of the steel is constant over the temperature range considered (approx. 1000–1500° C.).

For a rectangular slice of dimensions $2a$ by $2b$ and unit height, initially at the melting point θ_1, the heat Q lost when a shell of thickness s has been formed and the surface has cooled to a temperature θ_0 is :

$$Q = 4\rho s(a + b - s)L + 4\rho c\int_0^s (\theta_1 - \theta)\,(a + b - 2x)dx \quad (1)$$

where ρ is the density of the material, c is the specific heat, L is the latent heat of solidification, and x is the distance from the surface of the isotherm θ.

The temperature distribution is assumed to be parabolic along the axes, so that

$$\frac{\theta_1 - \theta}{\theta_1 - \theta_0} = \left(\frac{s - x}{s}\right)^2$$

and equation (1) becomes :

$$\frac{Q}{4\rho} - s(a + b - s)L = \frac{c(\theta_1 - \theta_0)}{s^2}\int_0^s (s - x)^2\,(a + b - 2x)\,dx$$

$$= c(\theta_1 - \theta_0)s\left\{\frac{a + b}{3} - \frac{s}{6}\right\}$$

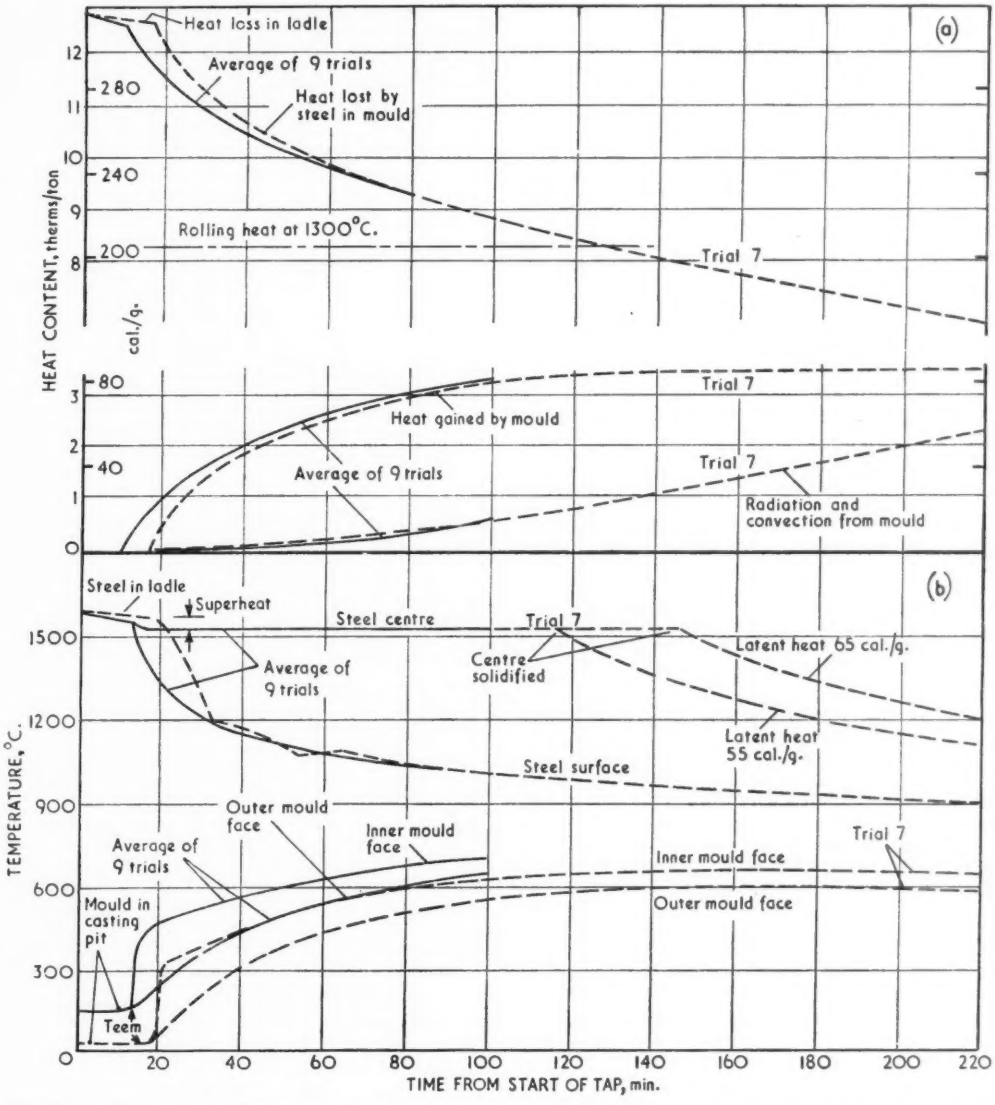
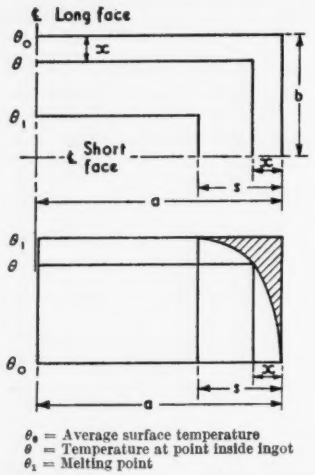


Fig. 11—Overall changes in heat content and temperature of mid-height slice of ingot and mould: (*a*) Change of heat content; (*b*) average temperatures



θ_e = Average surface temperature
θ = Temperature at point inside ingot
θ_1 = Melting point

Fig. 12—Representation of assumed temperature distribution in solidifying ingot. Heat loss is proportional to shaded volume

whence :

$$s^2\left\{L + c\frac{(\theta_1 - \theta_0)}{6}\right\} - s(a+b)\left\{L + \frac{c(\theta_1 - \theta_0)}{3}\right\} + \frac{Q}{4\rho} = 0$$

Similarly, maintaining the assumption of rectangular isotherms, after the material has completely solidified and the centre is at a temperature θ_c with the surface at θ_0, the total heat Q' lost in addition to the latent heat is given by :

$$\frac{Q'}{4c\rho} = \int_0^b (\theta_1 - \theta)(a + b - 2x)dx,$$

so that, since $\dfrac{\theta_e - \theta}{\theta_e - \theta_0} = \left(\dfrac{b-x}{b}\right)^2$,

$$\frac{Q'}{4c\rho} = ab(\theta_1 - \theta_e) - b\left\{\frac{4a}{3} - \frac{b}{6}\right\}(\theta_e - \theta_0)$$

and therefore $\theta_c = \dfrac{ab\theta_1 - b\left\{\dfrac{a}{3} + \dfrac{b}{6}\right\}\theta_0 - \dfrac{Q'}{4c\rho}}{b\left\{\dfrac{2a}{3} - \dfrac{b}{6}\right\}}$.

The average surface temperature θ_0 used in the above equations is obtained from the instantaneous heat flux F and the average temperature of the inner mould surface θ_m, assuming radiative heat transfer :

$$F = \varepsilon\sigma[(\theta_0 + 273)^4 - (\theta_m + 273)^4],$$

where ε is the effective emissivity of the surface (assumed to be 0·5) and σ is Stefan's constant ($1{\cdot}36 \times 10^{-12}$ cal./sq.cm.sec.[° K.]^4).

Acknowledgments

The authors express their thanks to Messrs. John Summers and Sons, Ltd., for permission to undertake the work ; to the management, staff, and operators of the melting shop, casting bay, and engineering department, for their assistance in preparing the test mould and carrying out the tests ; to the staff of the instrument section, for the measurements of the liquid steel temperatures ; and to the staff of the chemical laboratory, for the analysis of the ingot mould.

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1. A. V. Brancker, J. Stringer, and L. H. W. Savage : *J. Iron Steel Inst.*, 1950, vol. 164, pp. 67–84.
2. A. V. Brancker : *Ibid.*, vol. 165, pp. 307–313.
3. R. T. Fowler and J. Stringer : *Ibid.*, 1951, vol. 167, pp. 283–288.
4. R. T. Fowler : *Instrument Practice*, 1952, vol. 6, Feb., pp. 233–240.
5. R. T. Fowler and L. H. W. Savage : "Calculations of Ingot Temperatures from Mould Surface Temperatures." *Brit. Iron Steel Res. Assoc., Rep. No.* PE/A/50/50, Table I.

Correspondence on the Paper—
INTERIM REPORT OF SERVICE TRIALS OF STEEL COAL WAGONS*

By J. C. Hudson

Mr. **E. A. Tice** (International Nickel Company, New York) wrote : The Company with which I am associated had the occasion to follow the termination of a 20-year service test of coal hopper car floor sheets with one of the American railroads. This service test, begun in 1931, was a co-operative effort of the writer's firm, the Chesapeake & Ohio R.R., and one of the major steel companies. Ten 50-ton centre-dumping hopper cars were rebuilt with ¼-in.-thick floor plates of three steels, namely a 2% Ni – 1% Cu steel, a copper-bearing steel of 0·24% Cu, and a mild steel of 0·05% Cu. Each of the ten cars had the two floor sheets on one end equipped with low-alloy steel, and those on the other end either with mild steel or with one mild steel and one copper-bearing steel. There was a total of 20 low-alloy steel floor sheets, 5 copper-bearing steel, and 15 mild-steel sheets.

As a means of following the progress of corrosion, a drilled hole was located six inches from the bottom edge of each floor sheet midway between outside and centre side sheets, so that micrometer measurements could be made originally and at future inspection periods. The hole was filled with a rivet, during operation of the car. Such measurements were made at approximately two-yearly intervals, until the sheets deteriorated to a condition when they needed to be replaced. Unfortunately, the test could not be continued to ultimate failure of the low-alloy steel floor sheets, because the other parts of the car structures had reached their ultimate life and the cars were scheduled for complete scrapping in 1950.

Briefly, the service results were as follows :

Type of Steel Floor Sheet	Service Life
Mild steel	10–12 yr.
Copper steel	10–14 yr.
Ni–Cu low-alloy steel	Still useful at 19 yr. (estimated as 20 yr. at least)

* *J. Iron Steel Inst.*, 1951, vol. 169, pp. 250–256.

It was interesting to note that when the floor sheets developed perforations, at the bottom corners of the hopper section, the thickness at the measuring hole was about 150 mils, the sheets having lost about 100 mils at this location.

The life of mild steel and copper-bearing steel floor plates reported above is fairly typical of these steels in American coal hopper car service. The greatly extended life of the low-alloy steel points out the advantage of this type of steel for coal hopper car service.

The ten-year results, reported by Dr. Hudson, would indicate that the service conditions encountered in his study are considerably less severe than those found in American practice. There are several factors which differ in the two services, and which undoubtedly account for the difference in corrosivity.

In the first place, the British coals being handled in this study were given an alkaline wash at the colliery, so that alkaline drainings resulted. The drainings at the coke works were still alkaline, although the *p*H had dropped. In America, such alkaline washing at the mines is not a widespread practice, and the drainings are considered to be acidic in nature.

Secondly, the length of trip in the British test appears to be considerably shorter, and the frequency of loading much greater, than in American practice. Calculating from Dr. Hudson's tonnage and mileage figures, the British cars averaged approximately 50 miles per round trip and 8 – trips per month. In America, the average round trip is considerably longer, and there are only two to three trips per month. Consequently, the coal is in contact with the car body for a longer time per trip in American practice, and brings about longer periods of damp, acidic conditions on the steel surface. As Dr. Hudson's data indicated that the *p*H of the drainings decreased between loading at the colliery and unloading at the coke works, a longer trip time might have resulted in acidic drainings by the time the wagons reached the coke works.

On the other hand, the greater frequency of car loading in British practice should have a greater abrasive action on the steel rust coating and tend to accelerate deterioration. Apparently this factor is of secondary importance to the corrosivity of the coal drainings.

It is interesting to note the similarity of the pattern of distribution of corrosive attack in cars of considerably different design. In the British side-dumping cars, the most severe attack was found to be in the bottom end corner of the floor sheet, where coal dust can accumulate and damp conditions prevail. In American cars, first perforations usually occur in a similar position in the bottom corner of the floor sheet near the hopper opening. It has also been observed, by B. J. Kelly,* that the sheets fail near a supporting member, in a location of considerable flexure caused by the load and motion of the car. It is reasonable to presume that such flexing action fractures the rust scale and continually exposes fresh steel at these locations, which leads to greater deterioration of the flexed area.

Dr. Hudson has stated that "If it is assumed that perforation will occur when the average thickness has been reduced to 100 mils, the probable life of these ¼-in. floor plates will be about 28 years." In the floor-plate studies which the writer has made, perforation occurrence severe enough to require replacement of the plate occurs at a time when the average plate thickness is of the order of 150 mils. These observations would indicate that perhaps Dr. Hudson's assumption is rather optimistic. It would be interesting to know what range of average life is normally encountered on steel coal wagon floors in British coal-hauling service.

Dr. Hudson has suggested that, by substituting a low-alloy steel for mild steel in the coal-wagon body, a reduction in thickness of 20% could be made without decreasing the service life. This can probably be done, particularly in the less severe corrosive service encountered in his study. In America, a few experimental hopper cars have been built with low-alloy steels, incorporating a reduction in thickness of approximately 20% or slightly more. In one particular case with which the writer has been familiar, service life equivalent to the thicker carbon steel was obtained. However, it is the current feeling that these steels might better be used in the same thickness as customarily employed with carbon steel, and thereby obtain a longer service life.

For example, if a coal hopper car is to be used for 30 to 35 years, ¼-in.-thick carbon steel floor plates lasting 10 to 12 years would require two replacements, whereas side sheets lasting 15 to 17 years would require only one replacement. By using a low-alloy steel of the same thickness, a floor-plate life of 17 to 20 years would require only one replacement, thus saving one complete floor rebuilding shoppage. The economics of eliminating one floor replacement must be weighed against the higher cost of the low-alloy steel.

I should like to congratulate Dr. Hudson and his associates on this thorough field test programme.

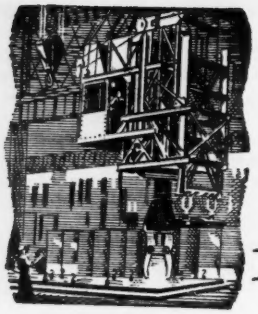
AUTHOR'S REPLY

Dr. **J. C. Hudson** wrote in reply: There is little that I need say in reply, save to thank Mr. Tice for his constructive comments, which materially add to the value of the observations. His remarks on the differences between the service conditions in Great Britain and the United States are particularly interesting, and I agree entirely with what he says. I agree, too, that I may have been a little optimistic in postulating that perforation of the floor plates would be delayed until their average thickness had been reduced to 100 mils. Experience may show that a higher figure is more appropriate. The general conclusion as to the advantages of using low-alloy steels would not, however, be invalidated.

In reply to Mr. Tice's question as to the average life of steel floor plates in British coal-hauling service, I find that this was given as 12 to 14 years in a reply by a chief mechanical engineer of a British railway to a questionnaire issued by the Corrosion Committee in 1929.* These plates would be of ordinary mild steel; their thickness, although unspecified, was presumably ¼ in. This is another indication that my estimate of 28 years may be too high; on the other hand, in the present tests the 12-year mark has been passed, and no major repairs have yet proved necessary.

* B. J. Kelly, *Corrosion Magazine*, 1951, vol. 7, pp. 196–201.

* First Report of the Corrosion Committee, *Iron Steel Inst. Spec. Rep. No.* 1, 1931, p. 20.



IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE SEVENTEENTH MEETING

THE SEVENTEENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Institution of Electrical Engineers, Savoy Place, London, W.C.2, on Tuesday, 4th March, 1952. Mr. C. H. T. WILLIAMS (The Park Gate Iron and Steel Co., Ltd.), Chairman of the Group, was in the Chair. The meeting was held in conjunction with the Royal Society for the Prevention of Accidents and the Training Committee of the British Iron and Steel Federation.

The MORNING SESSION was occupied by the presentation and discussion of a paper on " The Engineer and Accident Prevention in Iron and Steel Works," by Sir GEORGE P. BARNETT, H.M. Chief Inspector of Factories.

The AFTERNOON SESSION was devoted to the presentation and discussion of a paper by Mr. A. TAYLOR, Chief Safety Engineer, Richard Thomas and Baldwins, Ltd., entitled, " The Prevention of Handling and Lifting Hazards."

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 12.45 P.M.

The Engineer and Accident Prevention in Iron and Steel Works

By Sir George P. Barnett, K.B.

IN considering the rôle of the engineer in the prevention of accidents in iron and steel works one must deal with the wider aspect of accident causation in relation to plant and premises generally. The cause of an accident is often complex, but causation broadly comprises two main factors, usually concurrent: the physical and environmental factor, and the human and personal factor. I shall confine my remarks to the former, since preventive measures on that side are generally the province of the works engineer.

HISTORICAL BACKGROUND

The vicarious responsibility of factory managements for the safety of their employees has been recognized over a long period by the Courts, and certainly long before the Employers' Liability Act of 1880, recently repealed. The question of dangerous machinery and consequent factory accidents engaged the early Factory Inspectors; it was brought into prominence by the case of Cotterell and Stocks at the Liverpool Assizes in 1840. Judgment was given for a girl of 17, severely injured in a revolving-shafting accident, and damages against the factory occupier of £100, with £600 costs, were ordered to be paid. But for Lord Ashley, who sued the firm on her behalf, the girl would have received nothing; her employers had even deducted eighteen-pence for the period when she was unable to work. Some 18 years later a common law action was taken to the House of Lords, where Lord Cranworth expounded the doctrine of management's responsibility: " When a master employs his servant

Sir George Barnett is H.M. Chief Inspector of Factories.

in a work of danger he is bound to exercise due care in order to have his tackle and machinery in a safe and proper condition so as to protect the servant against unnecessary risks." Within three years this view was endorsed and it was indicated that an employer is responsible for want of care in providing good and sufficient apparatus and for failure to see to its proper use ; the obligation to provide and maintain proper plant and appliances was stated to be continuing. During this period there was also the collateral development of the safety provisions of the various Factory Acts of the last century, statutory clauses which have been rightly called " the worker's charter of safety."

THE ACCIDENT RATE IN IRON AND STEEL WORKS

Iron and steel works are considered to include blast-furnaces, melting shops and rolling mills, and their various ancillary operations. Such works produce less than 10% of the total accidents reported annually to H.M. Inspectors of Factories ; that is, accidents involving more than three days' absence from work. The pattern of accident causation in iron and steel works shows pronounced variations from the general pattern. The number of accidents due to machinery is slightly more than half as great proportionately, but the percentage of accidents due to fires, gassing, and burns is almost four times as great. The remaining discrepancies concern accidents due to hand tools and transport, for which the iron and steel works rate is half as great again as in all factories. The frequency of accidents due to the main causations expressed as a percentage of all accidents in iron and steel works is : machinery, 9% ; transport, 6½% ; electricity, 1% ; explosions, 1% ; fires, gassing, and burns, 6% ; hand tools, 13% ; falling articles, 10½% ; persons falling, 11% ; stepping on or striking against objects, 7% ; handling articles, 30% ; and miscellaneous, 5%. Iron and steel works account for nearly a quarter of all accidents due to power-operated lifting machinery in all factories. Only 1 in 360 accidents in factories as a whole is fatal, but the rate for iron and steel works is 1 in 240.

Accidents in iron and steel works arise from the same causes as elsewhere, although with greater frequency in some cases than in others. The desired reduction can only be achieved by studying these causes in detail and taking counter-measures, to prevent repetition, and to avoid those which might occur if preventive measures are not taken in time.

The smaller number of accidents on machines means that fewer accidents that can be prevented by physical safeguards such as the fencing of dangerous machines now occur. These must not, however, be neglected, and there is plenty of scope for preventive action on such dangers as bars which whip in reeling machines, roll intakes on straightening and flattening machines, guillotine blades, revolving-shafting gear wheels, couplings, pulleys and belts generally, crushing between work and the frames of shearing machines, scrap-bundling machines, etc. There are also those machinery accidents due not to danger inherent in the mechanism, but to that created by the mobility of the machine. A most serious and common risk concerns overhead travelling cranes trapping persons on the gantry when the crane is in motion ; a similar risk arises from the movement of charging machines.

Other risks can be obviated by providing safe working-places with safe access, firm and level floor surfaces, lifting machines and equipment of proper quality periodically overhauled and kept in good condition, properly maintained hand tools and appliances, good lighting, adequate ventilation, especially where inflammable or other dangerous gases are likely to be encountered, and effective protective clothing.

The number of accidents from causes which the above are aimed at preventing, and other accidents against which it is very difficult to provide specific preventive measures, can be reduced by the introduction and practice of safe methods of working. This involves care in personnel selection and consideration of the suitability of individuals for their tasks, competence and foresight in foremen and charge-hands, training and inculcation of safety principles for all employees, and the formation of works safety groups, with implementation of their recommendations.

PREVENTIVE MEASURES

In tackling the problems of accident prevention, one must not be overawed by apparently insurmountable physical difficulties. Don't be thwarted by the cramped conditions in old works, and don't overlook in the layout of new works the possibility of extension, as in the case of many existing works, where lack of foresight must be blamed for the present lack of space.

Lighting is very important in iron and steel works. Round-the-clock working, the spaciousness of the works, large outdoor working areas with constant movement of men and vehicles, and high-intensity glare are all factors requiring excellent general lighting.

Adequate and reliable communication between different parts of the works is very important. The departments of iron and steel works are often dependent on a distant source of power or heat in the same works. Such arrangements should take account of the fact that occasionally maintenance men work in isolated and dangerous positions. A recognized system should be followed rigidly when men have to work in such positions as gantries, furnace tops, gas mains, stove tops, etc. Where fitters, electricians, etc., have to go to any part which they do not know thoroughly, they should be accompanied by an experienced process man. Where work is done in an area liable to be affected by gas, look-out men should be posted. Breathing and resuscitative equipment should be provided and men trained to use it.

Elevated platforms should be fenced with double rails and toeboards, and access should be by stairs fenced with double rails on each side. Walkways on bunker tops should have guard rails. Trolley wires should be protected, and conveyor-belt mechanisms guarded.

Scrap yards should be large enough to permit proper stacking and to enable burning, cutting, etc., to be done on the ground and not on top of piles of scrap. Floors should be level and firm, and pathways

properly constructed and clearly defined, with adequate space between rakes of wagons. Floor plates should be secured, as accidents occur when loose plates are displaced ; where such plates cover gearing the risk of a person going through is not confined to falling, but may cause a machinery accident. Scrap boxes should be properly designed and maintained, and the bogies which carry them should be fitted so that boxes do not tip up or fall off. The layout should be such that men do not have to work or pass under magnet cranes.

Chargers should be able to slew in the shop span and not have to thread their way between columns, creating risk of crushing. Holes in floors should either be fenced or provided with covers which fit correctly.

The casting pit, the most dangerous part of the melting shop, should be wide and high enough to allow lifting to be done in safety. Casting immediately below the furnaces should be avoided. There men are exposed to heat from the furnace and, in the event of a breakaway, they are directly under the running metal. Casting platforms should have sufficient and wide exits for emergency use. There should be stairs at each end and, if the platform is long, others at frequent intervals. The stairs should not lead to the pit floor below the moulds, but to the outside of the building, so that the men get protection as soon as possible. Casting-pit floors should be level and solid, made of steel plates or similar material. If the floor is uneven, moulds may become unstable and fall over by contact with moulds swinging from the crane while being placed in position. In some works individual compartments have been built in which the moulds are placed so that they cannot fall.

In the rolling mill, driving gear to live roller gear and the gear driving cogging-mill manipulators should be securely fenced. The close fencing of dangerous parts is necessary whenever the parts may be approached, even though approach may be infrequent. Fencing has often not been provided until after an accident because it has been assumed that no one would approach gear wheels or the like. Bridges should be provided to cross continuous mills and convenient positions should be chosen to ensure use of the bridges.

Balance weights fitted to furnace doors should be totally enclosed over the full length of their movement. There should be adequate clearance between all railway lines and fixed structures and stacks of material. Where the lines carry hot-ingot bogies the clearance must be sufficient to allow men to pass the hot ingots in safety. Bogies moved by locomotive should be fitted with couplings which enable shunting poles to be used. Railway lines should be fenced where doors emerge directly on to them.

The nature of the work and prejudice on the part of workers are frequent excuses for not fencing the blade on large guillotine shears, although fencing does not usually involve any real difficulty.

Where guards are provided, constant vigilance is necessary to see that they are replaced after repairs. The guards not replaced are often those in rarely visited positions; a maintenance man who removes a guard to reach a part for repair or oiling may not replace it. Guards for the gearing, shafting, etc., on overhead travelling cranes are sometimes left off because of their inaccessibility. This risk would not arise if the guard need not be removed for maintenance ; guards should be designed so that periodical maintenance can be done with them in position.

Where it is not possible to provide secure fencing by fixed guards, a trip guard can often be used. When an obstruction with which a person approaching is obliged to come into contact is moved, the drive is stopped and the dangerous part comes to rest. There must not be sufficient lag after tripping for the person to reach the dangerous part before the machine stops.

Maintenance men are exposed to risk through lack of adequate precautions for their safety. When they are working on plant at rest, someone may start it up unintentionally or without knowing that men are at work upon it. This can be avoided by adopting one or more of the following precautions :

(*a*) Withdrawal of fuses from circuits controlling the parts on which work is being done
(*b*) Placing warning notices on switches
(*c*) Written permit system
(*d*) Logging of all switching operations
(*e*) Unified personal control.

The risk of persons being struck on overhead crane gantries is not only from the crane in the bay in which the person is working, but also from cranes in adjacent bays. When a man is working on a crane track he should be safeguarded from being struck by a crane on an adjacent track as well as by that on the track on which he is working. A crane may also be a danger to persons working remote from the track, but in a place near to where some part of the crane moves. A ladder upon which a man is working may be touched by the crane and cause him to fall. A window cleaner or a man carrying out repairs near the roof may also be struck.

Risk of cranes being overloaded increases when the loads cannot readily be ascertained. This is especially true of slag, the weight of which depends both on the size of the lump and on the metal content. An error in estimating such a load may result in the overturn or collapse of a jib crane, which would have serious personal and economic consequences. Where the weights to be handled by a crane cannot be ascertained with accuracy, the provision of an automatic safe-load indicator is desirable.

The proximity of manœuvring charging machines to men at work makes it essential to prevent men being crushed against fixed obstructions. The provision of a sound signal to enable the driver to warn anyone who might be endangered is desirable. The primary precaution is to eliminate such working positions, and much can be done by altering the positions of panels, levers, etc., which determine where men work.

The breaking-up of old castings by dropping a tup from a jib crane causes many accidents, both to those engaged on the process who fail to take cover from flying fragments, and to others at a distance who are unaware of the danger Such work should either be done in a pit lined with concrete or other material, or a deep shelter of steel plates or stout timbers should be erected around the site. The ball or tup should not be released until the person in charge of

the control rope is certain that no one is within the enclosure.

The tail ends of bars sometimes carry slag and so may become ragged during rolling. If in its path through the mill it meets an obstruction, the slag may be detached and thrown out violently. A gap in the floor plates between the live rolls (formerly occupied by a skid) has caused a fatal accident; after this the floor plate was extended over the gap to give a level and even floor.

When bars are being fed into a reeling machine they tend to whip if at all bent. Serious accidents have been caused by this. The only way to prevent them is to prohibit hand-feeding, and for the feed trough to be of channel section extending right up to the nip of the rolls with a **V**-shaped guide resting in it. Tongs grip the bar at a short gap in the **V**-guide and feed it into the nip. On smaller machines the trough is replaced by a tube extending right up to the rolls with a gap for the tongs to grip the bar and feed it into the rolls. The delivery side of these machines should also have a trough extending the full length of the bars.

EXPLOSION RISKS

The risk of explosion arises mainly about furnace plant. A serious explosion occurred a few years ago at the end of a blowing-out operation, owing to the too-sudden admission of water *via* the bell. The furnace was cooling on the day after the actual blow-out, water being sprayed on to the bell. The bell was open about an inch, but debris had choked the gap and a large bulk of water had collected on the top. The bell was lowered and the sudden admission of water to the furnace had disastrous results. An explosion from this cause can be avoided by the adoption of Fowler's method* of blowing out: ore alone is charged into the furnace at the end of the operation, and cooling water is not needed.

The biggest risk of gas explosion is at blowing-in and blowing-out, when gas in the mains and cleaning plant has to be replaced by air, or *vice versa*. To avoid the formation of a gas/air mixture the mains are purged with steam.

In the past, explosion doors have been provided on raw gas mains to relieve surges of pressure, as from a slip in the furnace. These doors must be self-closing to prevent admission of air to the mains and the formation of an explosive mixture. The doors should be self-sealing to avoid the need of approach for luting; sealing is usually achieved automatically by having the closing faces accurately machined. Self-sealing doors may, however, be difficult to maintain.

The modern tendency is to avoid the use of explosion doors altogether. The raw gas mains are built strong enough to withstand any surge of pressure. Elaborate gas cleaning smooths out any pressure surge by the time it reaches the clean gas mains, and reliefs are not necessary.

An explosion in the blast main can be disastrous, but it is fortunately rare in this country. It is caused by pressure going off the blast main; the blast air cools and contracts, sucking gas back from the furnace into the air main. When the blowers are restarted a gas/air mixture is blown forward and ignites at the furnace or a stove.

The following precautions are now standard practice:

(i) A pressure of 2–3 lb./sq. in. is maintained in the cold blast main by:
  (*a*) Spare blowers standing by ready to be switched on if a blower breaks down in use. Sometimes all blowers and furnaces are cross-connected, so that any blower may serve any furnace
  (*b*) Where there is no blast-furnace gas-holder, and blowers are driven by steam engines fed from gas-fired boilers, a temporary stoppage at the blast-furnace might lead to shortage of gas at the boilers; this could cause shortage of steam at the blower engines and loss of blast pressure. Coal or oil fires are always kept burning under some boilers in case of a shortage of gas.

(ii) Suction on the blast-furnace is avoided by:
  (*a*) Drop valves in the ring main that open to atmosphere when the pressure falls to 2–3 lb./sq. in.
  (*b*) Non-return valves in the mixing main to prevent the passage of gas, or valves that disconnect automatically when the pressure drops
  (*c*) Complete disconnection of blast pipes for prolonged stoppage.

In 1946 the British Iron and Steel Research Association prepared a code of practice, "Recommended Blast-Furnace Procedures," which covers explosion risks fully; detailed recommendations are given for ensuring the proper sequence of events in 16 situations in blast-furnace operation.

GASSING ACCIDENTS IN IRON AND STEEL WORKS

Gassing is responsible for many serious accidents in iron and steel works. During the period 1947–1950 31 persons were killed and 170 injured as a result of being gassed. Of these 47 (8 fatalities) occurred at blast-furnaces, 16 (1 fatality) at gas producers, and 107 (22 fatalities) in connection with the distribution and use of gas.

Gassing accidents may occur at any stage in the distribution and use of gas. Table I gives particulars of gassing accidents in steelworks over the last four years. The largest single cause of accidents is lack of precaution during maintenance work, and for this there can be no excuse, for in maintenance work the risk is known and appropriate precautions can be taken. Two examples will suffice. In the first case an explosion door in a pit had lifted; two men entered the pit to renew the luting without protecting themselves against gas, although it was leakage of gas that took them into the pit; both were seriously gassed. In another case the rope controlling a damper on top of a blast-furnace needed repair. Although gas was escaping freely, a man was sent up to work without protection: he was killed by the gas.

Wherever maintenance work is of a routine nature and risk of gassing is present, it is worth installing permanent compressed-air mains with frequent points of connection for air-fed facepieces or mouthpieces. At one works all the blast-furnace tops, the inter-

* *J. Iron Steel Inst.*, 1947, vol. 155, pp. 513–516.

mediate platforms, and the whole run of gas mains are so equipped. Where there is no permanent provision of air lines, self-contained oxygen or compressed-air sets should be worn, or use made of the ordinary smoke-helmet and air-hose apparatus.

For entry into flues, mains, stills, gas washing plant, and similar confined spaces, only two courses are open. Either:

(*a*) Full breathing apparatus must be worn; or
(*b*) The plant must be isolated, and the sludge removed from outside; the plant must be ventilated, and the atmosphere tested and proved safe; and an adequate supply of fresh air must be ensured.

A valve, even luted, or a water seal, or a single brick wall alone should never be relied on for isolation. It is best effected in brick mains by double walls purged between with steam or air, and in steel mains by blanking-off plates properly bolted down on packing, or by special isolating valves such as the McGee, Lodge Cottrell, or Bailey.

Much use is made in the steel industry of water seals, either as part of plant, such as a reversing valve of a gas washer, or to stop the flow of gas in a main when one part of a plant has to be isolated from another. All water-sealed devices depend for efficiency upon a proper head of water; even hourly inspection may not be enough to prevent a dangerous drop in water level. Recently a water seal was used as a temporary expedient to close the end of a blast-furnace clean-gas main. Despite periodical inspection, choking and failure of the water supply were not detected in time to prevent failure of the seal. Gas escaped in enormous quantity, catching many workers unawares; 11 men died of gassing. If water seals must be used, the bottom drain connection should be dispensed with altogether, or brought up to discharge at the normal level of water in the seal. This would involve pumping out the seal to empty it, but accidental draining could not occur. The level of water must be watched continuously to ensure that the water supply does not fail. Table I shows how regularly water seals are the cause of accidents.

More or less continuous leakage occurs from brick-built plant such as regenerators, furnaces, and billet stoves, particularly when plant is being lit up for the first time or after repairs. Constant attention is needed to keep leakage down to the minimum, and a high standard of ventilation must be maintained everywhere.

Both burning and gassing accidents occur from time to time during the burning-out of soot deposits from gas mains and flues. In many works gas mains are now fitted with steam-jet blowers, which blow soot and dust along to the dust catchers. The jets need to be turned on for an hour every fortnight; their use dispenses with the need for burning out the mains. Steam-jet equipment capable of withstanding the severe conditions inside a main is now obtainable. Where the older method of burning-out is used, certain precautions should always be observed:

> Air should be admitted first at the hottest end of the flue, where it will follow any residual gas in the main out to the chimney; it should never be admitted in the middle of a flue not cleared of gas and soot up to that point. Workers should never stand in front of a door while it is being opened, nor look in a doorway until the main is clear.

Useful information about precautions against risk of gassing is included in the following publications:

Table I

GASSING ACCIDENTS IN IRON AND STEEL WORKS, 1947–1950

Location	Cause	1947	1948	1949	1950	Total
Blast-Furnace	Bell jammed by feed material	...	1	2	...	3
	General leakage about plant	3	5	2 (1)	2	12 (1)
	Emptying dust catcher	...	2 (1)	1	...	3 (1)
	Gas-sampling burner not lit	2 (2)	...	...	...	2 (2)
	Water seal failing	1	...	2 (2)	2	5 (2)
	Maintenance	4	7 (1)	5	6 (1)	22 (2)
Gas Producers	Leakage at fuel charging	2	1	...	...	3
	Leakage from pokeholes	1	2	1	1	5
	Blow-back from purge pipe	...	...	1	...	1
	Maintenance	2 (1)	3	...	2	7 (1)
Distribution and Use of Gas	General leakage	12 (1)	5	9	5	31 (1)
	Underground mains leaking	...	2	1 (1)	...	3 (1)
	Gas tap left on	...	...	...	1	1
	Water seal failing	2 (1)	1 (1)	...	40 (12)	*43 (14)
	Maintenance	10	3	7 (3)	4 (3)	24 (6)
	Other causes	1	1	2	1	5
	Total	40 (5)	33 (3)	33 (7)	64 (16)	170 (31)

* Includes single accident—38 (11)

Ministry of Labour Factory Department :
Form 827—Carbon Monoxide Memorandum
(new) Accident Series :
2/19—" Fire Extinguishers "
5/11—" Isolation of Gas Mains "
6/25—" Water Seals "
7/17—" Tapping Furnaces "
Ministry of Fuel :
Fuel Efficiency Bulletin No. 44—" The Operation of Gas Producers "
British Iron and Steel Research Association :
Recommended Blast-Furnace Procedures.

RADIATION DANGERS

There has recently been much expansion in the industrial use and in the power of X-rays for the radiography of castings and welds in iron and steel foundries. The increasing availability of suitable and inexpensive gamma ray emitting radioactive isotopes has increased the use, for similar purposes, of these artificial radioactive materials to supplement radon and radium.

X-ray sets of 250–400 kV. rating are almost normal equipment in most iron and steel works nowadays, and in special circumstances powerful sets up to 2000 kV. have been installed. Correspondingly powerful sources of gamma radiation from cobalt 60, tantalum 182, and iridium 192 in strengths up to and around 1 curie (equivalent to 1 g. of radium) are used to supplement the sources of X-radiation.

It might have been expected that with such powerful sources of ionizing radiation in use under factory conditions there would have been a number of serious accidents, but fortunately they have been rare ; the problems in this radiological field are much more related to health protection than to accident prevention.

Only three cases of X-ray burn have been reported to the Factory Department from iron and steel foundries, all similar to that described in " Accidents, how they happen and how to prevent them," 1950, vol. 5, New Series, No. 9. The cause was failure to provide all entrances to X-ray rooms with electrical interlocks and warning lights to ensure that the X-ray tubes within cannot be energized until all entrances are closed ; the control panels are situated outside completely enclosed X-ray rooms whose walls (and ceilings and floors where necessary) are of full protective thickness.

No accidents have yet been reported from the use of powerful gamma-ray sources. This was to be expected, since X-ray tubes produce more concentrated radiation than gamma-ray sources.

This good record is due to the industry's careful attention to such matters as the correct construction and protection of X-ray rooms, shockproof X-ray tubes and associated equipment ; the exclusion of workers from X-ray rooms during radiographic exposures and from defined areas around gamma-ray sources ; the provision of interlocking arrangements and warning lights in X-ray rooms ; the provision of adequately protected, and, where necessary, ventilated safes or boreholes, and of protective carriers for the storage and transport of radioactive sources ; the use of remote control or automatic clockwork-controlled methods of removing radioactive sources from their carriers ; the testing of workers' radiation exposure by the use of personal film badges and by instrumental monitoring ; skilled and competent supervision of the safety and health precautions ; and routine clinical and haematological examination.

Although the Department has not yet made regulations for the protection of workers in the field of industrial radiology, this is in mind ; meanwhile a useful code of good practice exists in the " Recommendations of the British X-ray and Radium Protection Committee," 7th Revised Report (October, 1948), and in Chapter XI, " Dangerous Radiations," in the International Labour Office " Model Code of Safety Regulations for Industrial Establishments."

DISCUSSION

Sir **George P. Barnett** (H.M. Chief Inspector of Factories) read his paper on " The Engineer and Accident Prevention in Iron and Steel Works."

Mr. **J. Sinclair Kerr** (Lancashire Steel Corp., Ltd.) : I am Chairman of the Manchester Industrial Group for Accident Prevention, and Chairman of the Lancashire Area Training Committee of the British Iron and Steel Federation, which hold meetings and discussions, and courses for foremen as well as apprentices and juveniles. Foremen selected from various companies are given a four-day course at which papers are read by H.M. Factory Inspectors. This is very necessary because the latest safety appliances do not give full value without direction and sympathetic control from the manager and the foreman.

There is another side to accident prevention—the human side. Workmen are human beings, with varying temperaments and psychology, and each must be treated differently. A man may become careless ; if the Accident Prevention Committee talk reasonably to him and make him feel that they understand his job and have his welfare at heart, good results will follow.

Gas-cleaning plant demands the closest possible attention. In our case, the sequence when changing treaters for cleaning is as follows :

> The blast-furnace assistant manager obtains a signed certificate from the engineers stating that the plant is safe before being opened up. The treaters are purged with steam. A certificate is obtained from the fuel officer that the atmosphere inside the treaters is clear of CO. The spring-loaded explosion covers are removed and replaced by perforated plates painted red and marked ' Danger.' Before the treater is put into operation, a certificate is again given by the engineers that the plant is safe and ready for operation. Two samples are taken to ensure that there is no air in the gas before it is opened out into the gas holder.

For blowing out furnaces, we use the Fowler system ; one merely has to use raw stone, which keeps the furnace top cool, and the calcined stone can be used on the burden

at another furnace. It is economical and safe for the workmen.

I do not know whether steaming-out gas mains is good practice. At one of our collieries we had some very fine producer coal, which gave a rich gas, but which deposited tar along the tube. We tried jets of all diameters. The main was about 1120 ft. long. We cut it in two, and then in three, with no success. Finally, we used oil for some of the furnaces, and now coke-oven gas and oil. I hope that before long we shall end that wasteful system of using producer gas.

I have had long experience in pioneering accident prevention, and I hope that as a result of this meeting we shall be able to cut down the number of accidents. There are 250,000 accidents a year in all industries, as a result of which £15 million are lost to the nation. But this does not indicate what is lost to the home, or to the man who loses a leg, or to those who are left when a man loses his life. We must look to the human side.

Sir **George Barnett** : It is very important that managers and foremen should be closely associated with accident prevention. The foreman is, or should be, the key man in any works accident-prevention organization.

Mr. **T. W. Thursfield** (Gjers Mills and Co., Ltd.) : The use of steam in mains and dust catchers for preventing gas explosions is sound and successful in practice. One must be sure that the steam is passing into the dust catchers and mains, particularly on the dirty gas side. At one plant where steam had not been required for some time the entrance was blocked with flue dust ; when the valve was opened, no steam passed through. It is good practice to fit two valves in the steam line with a four-way coupling between them, when it is possible to test the steam through and keep the last portion clear of dust.

We find the meetings of the Accident Prevention Committee most helpful ; all accidents are discussed, often resulting in alterations to plant or procedure to prevent similar accidents.

Safety boots and shoes are very popular in all departments. Many foot accidents would not occur if workers used protected footwear instead of light, badly worn shoes or boots.

All cabins near furnaces should be fitted with two doors or an escape hatch. If there is any possibility of gas leakage or break-out blocking one entrance, the occupants should be able to get out safely.

Transport is very important in accident prevention. How many times does a worker crawl between or underneath stationary wagons ? The loco may hit the wagons at the other end, or somebody may take off the brake and cause them to move, if they are on a slope.

Cleaning-up after a repair or engineering job is very important. All footways and working roads should be kept clear of rubbish, and all gear removed from them.

Mr. **J. MacColl** (H.M. Superintending Inspector of Factories) : In the iron and steel industry last year in one North Midland district, there were 13 fatalities, of which eight were to men not directly employed by the factory occupiers. Every factory is in a constant state of transition, and at some time every department has outside men within it.

It is the rule in accident statistics prepared by factory occupiers to disregard accidents to persons not directly employed. If the engineer would consider what goes on in the whole plant instead of considering his own men more than outside people, safety would be increased throughout the plant, and not only in regard to the contractors' men.

Firms should include in their returns accidents to outside contractors. Under the Factory Acts, unless the work is an actual building, upon which a smaller proportion of the contractors' men are generally engaged than in other contract works, an accident to any such men is legally notifiable by the factory occupiers and not by the contractor, whose legal obligation is to report the occurrence to the occupier immediately. Even those accidents which are so notifiable by the firm to the Inspector are generally not included in the firm's own statistics.

Mr. **E. S. Harrison** (English Steel Corp., Ltd.) : Some accidents are caused by the negligence of employees. The modern tendency places the responsibility upon the management. The Factory Acts, although full of what the management must and must not do, say little about employees' responsibilities. Even when an employee violates a regulation, he is seldom taken to court. Would not a few more prosecutions have a good effect, as, for instance, when employees refuse to wear goggles when concerned with processes for which it is compulsory to provide goggles ?

Sir **George Barnett** : If adequate and suitable evidence is provided to the Factory Inspectors, they will take proceedings under Section 119, where that Section applies. But the Factory Acts are for the protection of the worker, and the vicarious responsibility of the occupier is onerous.

Many accidents occur because workers do not use the safeguards provided, but inspectors can rarely get adequate evidence to place before a court. This must include information that the firm has taken all due diligence to see that the Act has been observed ; in law due diligence means more than mere instruction. In a recent common-law case for example, a worker who had been injured successfully claimed damages where, although the firm provided goggles, these were in the foreman's office and not immediately available.

I particularly stressed in last year's Report that the regulations dealing with the protection of eyes, under Section 49, are not well observed, in some cases by workers and in others by managements. If however we are to take more cases against employees we must first have adequate evidence that the firm has used all due diligence. This means that there must be more detailed inspection and supervision, daily or more often. If that is done, we ought to have ample evidence available on which to proceed against employees for failure to wear protective devices and to use the guards provided.

Mr. **J. H. Groocock** (Steel Company of Wales, Ltd.) : Distribution systems in iron and steel works are tending to become larger and more complex. At the plant with which I am associated, we have 35 E.H.T. sub-stations ; we have always operated an E.H.T. permit system, but we decided that it could not cope with rapidly changing conditions. It took us about a year to prepare a new scheme, which was as nearly foolproof as possible, while retaining sufficient flexibility to make it practical. During this time we had valuable help from H.M. Electrical Inspectors. The permit system is useless unless it is made as watertight as possible, which is no light task.

Particular care should be taken in the selection of authorized and competent persons in the sense of the Electricity Regulations. These people should be kept as few as possible, and they must be capable of carrying out the duties under both heads.

The essence of the matter lies in the words on the permit: ' Nature of the work to be carried out.' It is very difficult indeed to get even very intelligent people to realize that one must be absolutely precise when putting down on the permit the nature of the work that it is intended to carry out. On an E.H.T. system there is no

room for vagueness and generalities when working on high voltages. It is sometimes found necessary, when the work has started, to do more than was at first anticipated; in this event the permit in use must be cancelled and another issued. It is never safe to extend a permit, because some of the copies may not get the additional information put on them.

Sir **George Barnett**: Permit systems must be made as foolproof as possible, and there should not be too many authorized people.

Another type of authorized person in a factory is a machinery attendant under the Operations at Unfenced Machinery Regulations. Some firms give special certificates to too many machinery attendants to do dangerous work in relation to unguarded machinery.

Mr. **J. T. Dunn** (H.M. Inspector of Factories): The usual gear for lifting the doors of furnaces in steel-melting shops and in reheating furnaces is a chain attached by a shackle, or, much worse, by a **C**-type hook. In moving up and down, and when exposed to the heat of the furnace, there may be failure in the lifting system. In most furnaces, the door will fall forward, and anybody who is in the way will be both crushed and burnt.

Measures should be taken to prevent that type of accident, which is infrequent, but which may happen at any time. The best method is to take measures in the design of the furnace opening. The door should run in guides which are part of the furnace. With older furnaces, where this is not practicable, I have seen two other methods adopted. One is the permanent attachment of subsidiary chains which take no part in the actual lifting, but which, if the suspension fails, stop the door from falling outwards. The other is the use of latches, attached to the buck-stay and projecting over in front of the edge of the furnace door to stop it falling. These two methods require supervision to ensure that maintenance men replace the chains or latches.

Falls through the openings sometimes left in melting-shop floors for getting bricks up and debris down after repair of the furnace can usually be prevented by means of movable covers. The charging machine would knock down the ordinary type of fencing. When covers are provided some means must be adopted to ensure that they are used and replaced. It is expecting too much of operatives to have a heavy cover which requires half a dozen men to move it. If the cover cannot be sectionalized so that two men can move it, some form of motorization should be provided; the cover may be moved from below the melting-shop floor.

I have no solution to offer on how to protect the edges of openings left in melting-shop floors above mixers.

At the ends of the melting shop there is often a fall on to the rail track below. Most works attempt to provide fencing for this edge, but it is very difficult to maintain. It often has to be removable so that the crane may bring materials up and over the edge; if it is not removable the crane driver soon removes it. The following alternative method might be adopted: an inclined ramp, made so that a man could not stand on it, would ensure that if he fell over he would not fall the full 20 ft. to the ground, but only a few feet. This method might stand up to the working of a crane.

Loco accidents are almost always serious. They must be reduced largely by tackling the human factor in accident causation, but the engineer can do a little. Usually all that is provided to prevent the movement of wagons down an incline is a triangular-shaped piece of wood which soon gets crushed and is then replaced by any other piece of wood lying around, or even by bits of brick. In some steelworks steel chocks with handles are used, so that when a man is putting the chock in position he does not risk having the wagon run back and crush his fingers. These can be staked by a long chain to ensure that they are not removed. Wooden chocks should be properly constructed, with handles so that they may be inserted in safety.

The problem of silicosis among labourers engaged in dismantling steel furnaces does not strictly fall under the heading of accident prevention, although it could be an engineering matter. So far no one has solved the problem of preventing men from breathing the dangerous silica dust from the brickwork; it might be solved by engineering methods, so that for preventive measures we would not have to rely on respirators, which are uncomfortable in the hot conditions of repairing a steel furnace.

Mr. **E. Doughty** (St. Anne's Board Mill Co., Ltd.): Although factory management must be finally responsible for ensuring the safety of all equipment used, the overall responsibility has sectional aspects as follows:

Manufacturers must accept full responsibility for supplying equipment adequately guarded, giving safety during operation and maintenance. Designers concentrate mainly on the former, but safety during maintenance is equally important. Manufacturers employ their own safety officers—men of considerable works experience who could advise in the design stage, during shop erection, and after the equipment has been commissioned. Site modifications are too often left to the erection chargehand or foreman. Manufacturers should issue a certificate that equipment has been approved as being adequately guarded. Do manufacturers consult the Factory Inspector, or does he visit manufacturers' works?

Management must always be finally responsible for ensuring the safety of all equipment, and the person most intimately concerned is the works engineer. He cannot attend to all matters personally, and certain duties must be delegated. The firm with which I am associated appointed, four years ago, two inspectors, one electrical and one mechanical, whose duties embrace the safe working of all lifting appliances. Inspections are made at more frequent intervals than required by the regulations and many items are checked between routine inspections. Urgent matters are dealt with immediately; maintenance is done by men who work only on lifting appliances. Since their appointment, there has been a marked reduction in the number of outages and several defects have been rectified in their early stages and possible accidents avoided.

To protect maintenance men, the withdrawal of a fuse, supplemented by a warning notice, is inadequate. The only safe way is to isolate and lock off the control unit, accomplished best by fitting each control unit with an isolator which can be locked in the off-position. Maintenance men must be provided with padlocks with non-interchangeable keys, and control units must be accessible and clearly labelled.

Most firms operate permit schemes. Before a permit can be issued, an authorized person must make safe and lock off. A big factory would require a large number of authorized persons, and so the scheme is confined to certain areas, the selection of which requires careful consideration. In my firm, drawings of the electrical system are posted throughout the works. A boundary line on the drawing defines the permit area, inside which an authorized person makes safe, locks off, and issues a permit; outside, the tradesman is responsible and works under the supervision of his chargehand or foreman. Tradesmen are classified according to the Factory Act as competent and non-competent.

Permit schemes are applicable to services other than electrical systems, *e.g.*, steam, water, compressed air, gas. In the Electrical Regulations, responsibility is

divided into two grades, authorized and competent; equally clear grades should be defined for trades other than electrical.

Employees are responsible for performing operation and maintenance duties in a safe and tidy manner, and for reporting any defects they observe. This requires men of high intelligence with a sense of responsibility. When an employer engages a man, he expects him to know something of the job for which he is being employed; the employer will provide specialized training. Very few employers insist that men should have knowledge of industrial safety, which is basic, and not specialized. Apprentices, for example, learn the basic theory of their trade at continuation classes, but industrial safety is not taught. Few people are really safety conscious, but suitable training will reduce the accident rate. Many firms give lectures in safety methods and practices, but unless these are repeated frequently the lessons are forgotten.

Sir **George Barnett**: Manufacturers of machinery and plant should come into the picture much more; safety should begin at the design stage. The Engineering and Chemical Branch of the Factory Department spend a lot of time with the manufacturers of all sorts of plant and machinery, who now approach us a great deal when they have new types of machines in mind to discuss technical points on safety, but they could do a great deal more in that direction than they do. They have certain responsibilities under Section 17 of the Factories Act but there are disadvantages in requiring too fine a specification of safety for machines for all industries and processes; this might well inhibit progress in the development of safety in machines.

One of the great points which has come out of the visits of Productivity Teams to the United States is that in this country we have higher standards of safeguarding plant and machinery, but at least twenty of the Teams have emphasized that people in the United States are more safety conscious than we are. If we can increase safety consciousness in our factories, both on the side of management and of workers, and still maintain and improve our safeguarding, we shall make big strides in accident prevention.

I think that safety consciousness must come from better education and training, which must be continuous. Youngsters must develop the habit of working safely, but you must also bring safety into courses for management and foremen.

Mr. **A. Clifford** (Appleby-Frodingham Steel Co.): In 1948 my company had 547 accidents, giving a frequency rate of 3·27, at which time we only had a main safety committee. In 1949 a few sub-committees were formed, and we reduced our accidents to 415, and our frequency rate to 2·3. There was still room for improvement, so we formed more groups, until in 1951 we had 16 separate sub-committees, each dealing specifically with safety and responsible to its own department. With the help of these groups we reduced our accidents to 314 and our frequency rate to 1·73.

All attention possible should be given to the formation of such groups or sub-committees.

Sir **George Barnett**: We cannot give a national frequency-rate figure because we can only rely on voluntary statistics. Firms are not obliged to tell us the number of man-hours lost through accidents in any particular year. In the 1950 Report, statistics relating to 110 steel firms are given, representing over 154,000 employees; the average frequency rate for those firms was 3·28, compared with an overall average rate, from 1700 firms in different industries, of 2·1. There are many steelworks where 3·28 is considered high, many having reduced it well below that figure.

It is essential that the reasonable recommendations of safety committees are properly implemented by the management.

Mr. **E. W. Huddy** (H.M. Inspector of Factories): The nip between a conveyor belt and the end pulleys and the belt and the snub pulley is very dangerous. In the last two years in my district I have had two fatal accidents at this nip. It is quite easy to fence at a distance so that a man cannot reach the nip, and this should be done in every case.

Accidents have ocurred at the idle rollers. These are not usually fenced, but there are two or three places where they should be. Where the return part of the belt runs underneath a steel plate between the two belts, and the distance between the idle rollers and the steel plate is a few inches, there is a dangerous nip between the idle rollers and the belt.

The problem of the large hole required for taking hot metal up from the mixer or the large hole in front of the mixer has been solved by having a large plate which slides underneath the melting-shop platform and is mechanically operated, and which slides back and covers the hole as soon as the ladle is taken away. There is a short drop from the platform to the plate, but the plate prevents falls to the floor below.

We are dealing vigorously in the North Midland division with the question of the mechanical feeding of bar-reeling machines. In the Sheffield area there have been a number of accidents with tongs, and we have tried to do away with any feeding by hand or by tongs, with a certain amount of success. We have also nearly solved the problem of coupling and uncoupling ingot bogies by making it unnecessary to go between the locomotive and the bogie, or between two bogies.

Mr. **H. Demaine** (Park Gate Iron and Steel Co., Ltd.): The removal of fuses by anyone other than an electrician should not be permitted, because it encourages the amateur electrician to go further than removing them for safety to repair them when they have blown.

Portable electrical tools, such as drilling machines, hand grinders, and electric hammers, should be wound for operating from a 50-V. supply. Where the demand for tools is frequent, a permanent 50-V. supply is justified; a 230–50 V. portable transformer can be taken to the sites where the demand is less frequent.

Existing tools wound for 230 V. can be operated from the 50-V. supply by using a step-up transformer with an unearthed secondary. These portable transformers are housed in robust wooden boxes, and have proved very successful at my company.

New portable tools should be ordered by the electrical engineering department, and not by anyone in a position to order equipment.

Many temporary lights are required in an iron and steel works. My company now install all their temporary lights at 50 V. using 300-W. lamps specially frosted so as to be easily recognizable, and to reduce glare and dazzle. They are operated from permanently installed 50-V. supplies, or from portable transformers.

Mr. **J. J. Kelly** (St. Anne's Board Mill Co.): Guards are usually made of 16-gauge material fastened on with small screws, and will not stand removal more than once or twice before being damaged beyond recognition. Why are guards made in this way? They do not normally have to carry stresses from the machine function, but invariably suffer through mishandling by the machine operator. They should be made to at least the same standard of strength as the machines to which they are fixed, so as to last the lifetime of the machine.

Machinery attendants should be drilled once a year. The machinery attendant's certificate does not give him the right to do as he likes ; there are many restrictions and rules to be observed if the certificate is used properly, and about which attendants are often unsure. For instance, if a machinery attendant has to remove a guard for some purpose, is he allowed to take the guard away regardless of what is inside or what he is looking for ? The interpretation put upon the Regulation and the appropriate Sections of the Factory Act is that only the part being investigated may be exposed at any one time.

Sir **George Barnett** : Under the Operations at Unfenced Machinery Regulations it must be shown to be absolutely necessary to have the part that you are looking at running during the examination and impossible to do what you want with it stopped. The Regulations lay down that it is not permissible to take all the guards off the machine ; you are allowed to take off only such fencing as will enable you to reach the particular part that you want to examine, the part that you must have running for the examination.

Mr. Kelly's problem was somewhat difficult, because presumably there the management had provided an overall guard to protect various different parts of the driving mechanism. Whether a court would hold that you were not entitled to take that guard off to examine a part which must necessarily be running, I should not like to say. But there is a condition in the Regulations that you must not generally expose the running parts of the machine, but only the part which it is necessary to examine and which must be running for that examination. There are however very few instances where it is necessary to have a part running while it is being examined or repaired.

Mr. **L. George** (Park Gate Iron and Steel Co., Ltd.): Within the steel industry there are occupations for which no provision for protection of the eyes is made in the Regulations. To overcome this problem, my company has approached the unions concerned with regard to two such occupations: chipping bars with pneumatic tools, and sawing hot bars with fixed revolving saws. What would be the position so far as the occupier of the factory is concerned if we claimed that, having an agreement with the unions, we would like the Factory Inspectorate to back us up by adding those occupations in the schedule?

Sir **George Barnett** : In any possible common-law action, if the worker's occupation was not within the schedule, there could be no breach of statutory duty, so it would be for the court to consider whether or not there had been negligence on the part of the management. I cannot say what the court's decision would be in this event without much more detailed evidence of the circumstances.

CORRESPONDENCE

Mr. **K. E. Jermy** (British Iron and Steel Research Association) wrote : Two points should be mentioned in connection with the pamphlet ' Recommended Blast Furnace Procedures,' which was drawn up by the Blast Furnace Practice Committee of B.I.S.R.A. in 1946. Firstly, the Committee realized that no codes of practice could be drawn up which would be applicable to all furnaces at all works, in view of the different conditions found at various plants (*e.g.*, single- or multiple-furnace working, hand or mechanical charging systems, common or individual blowing, etc.). The ' Recommended Procedures ' must therefore not be regarded as codes of practice, but rather as notes, applicable to sixteen blast-furnace operating situations, which can be used by individual managements as a basis for drawing up their own local safe-working methods. Secondly, ' Recommended Procedures ' is not an open publication ; it has been made available, under the normal arrangements of restricted circulation, to firms which are members of B.I.S.R.A.

PROCEEDINGS OF THE AFTERNOON SESSION : 2.0 P.M. to 4.0 P.M.

The Prevention of Handling and Lifting Hazards

By A. Taylor

THE duties of a safety officer are creative in the broad sense only. One of his functions is to make suggestions and submit ideas for the removal of hazards. The application of these suggestions or ideas is then a matter for the technical staffs. I shall present, therefore, a general survey of the problems of accident prevention as related to handling and lifting without entering into technical considerations.

In many cases it seems necessary for an accident to occur before preventive action is taken. I would emphasize the overriding influence of the near accident, that is the accident which nearly causes injury.

I was called to a works in Yorkshire some years ago to investigate the cause of an accident. A 62-year-old man, who had been at this works since his boyhood, was killed while carrying out an operation which he had done without injury for 20 years. I was able to correct this operation, and was asked to survey the whole works ; all my recommendations, involving a large expenditure, were agreed to. This man had to be killed before the management woke up to their moral and statutory obligations.

There are many publications relating to handling and lifting, and there is also " The British Standards of Lifting Tackle," but it is not in relation to their application that I wish to talk. I want to show the need for effective supervision and care in the organization of all handling and lifting operations, and in the use of mechanical aids.

The importance of accident prevention can be seen from the latest figures issued by the Chief Inspector

Mr. Taylor is the Chief Safety Engineer of Messrs. Richard Thomas and Baldwins, Ltd.

of Factories in his Annual Report. These show approximately 200,000 notifiable accidents in industry during 1949 (the latest available report), nearly half of which come under the heading of lifting and handling. Of this total, 54,811 were due to moving goods and articles, 17,841 to use of hand tools, 17,705 to being struck by a falling body, 4389 to powered lifting machinery, and 1278 to other lifting machinery.

These are notifiable accidents, involving a loss of three days or more; no account has been taken of accidents as a result of which the workman loses only one or two days' employment, or of those accidents which do not cause injury, but which waste material and plant, and interrupt production.

ACCIDENT COSTS

Most methods of estimating the cost of an industrial accident are based upon the compensation paid to the injured worker. There remains what may be termed the 'hidden cost.' This has been estimated by Heinrich, the American safety engineer, to be four times the known cost.* The reasonableness of this estimate has been shown by analysis of the accident records of many plants.

It is not contended that the proportion of four to one holds good for every industrial plant, but on the whole it is correct.

Calculations from which this ratio was derived were based on the following factors of hidden costs:

(1) Cost of lost time to the injured person
(2) Cost of time lost by other workers who stop out of curiosity or sympathy to assist the injured person, or for other reasons
(3) Cost of time lost by executives in assisting the injured man, investigating the cause of the accident, selecting, training, or breaking in a new workman to replace the one injured, and preparation of accident reports, etc.
(4) Cost of damage to machinery, tools, property, or material
(5) Incidental costs due to interference with production and failure to complete orders on time
(6) Costs due to the loss of profit on the employee's productivity and on idle machines.

This loss does not include all the points which might receive consideration, but it outlines a cycle of events which follows accidents.

An example of the application of this ratio can be seen from the experiences of a firm of contractors on a building contract. During the period of the contract there were 72 accidents. The injuries were fractures, contusions, burns, and bruises, and the causes were classified as falling material, slipping, and falling.

The costs, compensation and medical, were estimated to be £72. Incidental costs were computed as:

	£
Time lost by other employees	107
Time lost by foreman and supervisors	27
Property damage	54
Payment for failure to complete contract on time	69
Total	£257

The safety officer of one large firm analysed the effects of a typical accident and circulated the result to other members of the staff. A skilled machinist, doing a key operation on an important export commodity, met with an accident that caused severe abdominal injury. Three workmates went to the man's assistance. The departmental first-aid attendant tended the victim before removal. A stretcher party was required to carry the man to the Ambulance Room, whence he was removed to hospital. Later, owing to the seriousness of the accident, an investigation was held, attended by the works manager, works engineer, shop manager, charge-hand, and safety officer.

So far, the loss of production time could be summarized thus:

(*a*) The victim: total stoppage of production
(*b*) The stretcher party, the first-aid attendant and the three men who went to the victim's assistance: temporary total stoppage of production, followed by slackening due to discussion of the accident and to psychological effect
(*c*) Remainder of the shop: slackening of production during the passing of the stretcher and subsequent discussion; psychological effect
(*d*) Works manager and other members of investigating team: away from normal work during period of investigation.

Several other people also lost production time, and to the above were added:

(*e*) The man who took the place of the injured worker had to be trained; during training he worked more slowly than the victim and was liable to spoil material
(*f*) The charge-hand instructor was taken from his normal work to train the new man
(*g*) The injured man's wife gave up her part-time job in another factory to look after her husband
(*h*) The injured man's relatives, working in similar conditions, suffered from psychological reaction and for a time their production suffered.

Another ratio relating to accident cost is Heinrich's 1 : 29 : 300 ratio†; data available to him showed that in a unit group of 330 similar accidents, 300 resulted in no injuries, 29 in minor injuries, and one in a major or lost-time injury. The entire 330 accidents were due to the same cause, and could be corrected by the same remedy. He draws the moral that in an industry where employees work under supervision the opportunity exists for correction by the supervisor, who must notice some of the unsafe practice before an accident occurs.

Apart from the moral aspect and the obligation to avoid action or lack of action which will cause suffering, in these days of manpower shortage industry cannot afford this wastage.

LIFTS AND HOISTS

Various Governments have been concerned with the high accident ratio with lifting and hoisting machinery, and several sections of the Factories Act 1937/48 were devoted to this. The Act places certain duties and responsibilities upon the employer, and, under Section 119, the employee. It might appear that if everyone carried out these requirements and observed the various Special Regulations, it would be almost impossible for an accident to occur. Unfortunately

*H. W. Heinrich, "Industrial Accident Prevention," p. 51, New York, 1950, McGraw-Hill Publishing Co.

† *Loc. cit.*, p. 27.

the human element enters far too often into the picture, with results that are often disastrous.

Section 56 of the 1937 Factories Act provides that a young person may not lift, carry, or move any load heavy enough to cause injury to him. It also empowers the Secretary of State to make special regulations as to weight lifting by any class of persons employed in a factory. The elimination of manual lifting by the substitution of mechanical methods is the most likely way to reduce the number of accidents due to this cause. The most prevalent injuries are hernia, strain, traps, crushing, abrasions, and cuts, most of which could be avoided by a proper lifting technique. Numerous charts are issued showing the correct method of lifting and grasping objects. A wide field exists for safety education which would result in a reduction in injury and lost time.

Safety Pamphlet No. 16, "Weight Lifting and Industrial Workers," issued by the Ministry of Labour Factory Department, provides much valuable and detailed information on this subject. Section 22 contains specific instructions on the design and use of hoists and lifts, which are defined as lifting machines, where the platform or cage is restricted in movement by a guide or guides.

The Chief Inspector's Report shows that lift accidents are mainly caused by :

(1) Suspending-rope failure
(2) Defects in lift or hoist well enclosure and doors such as to permit people to fall down the well
(3) Persons injured through becoming jammed between moving parts of the lift, and between moving parts and fixed structures.

The chief cause of the first type of accident is usually inefficient maintenance rather than faulty rope manufacture. The second is another hazard which should never exist. Proper attention to the well enclosure and gate interlock should remove all possibility of accidents resulting from these defects.

The third can usually be avoided by proper attention to maintenance of the hoisting machinery, brakes, etc. Two accidents in connection with this are worth mentioning.

In a lift being installed it was found on test that the counterbalance weights were too light. The lift was taken to the top of the well and left with the brakes fully applied. A man entered the well to change the weights ; as soon as he had removed them for replacement the lift descended, the rope slipping on the stationary drum ; the cage fell 60 ft. and crushed him. This should have been expected when the weights were removed. In such cases, the cage should be lashed to the top beam, or suitable joists placed across the well beneath the cage on which its weight could be taken. Slots should be made in the brickwork of the well to accommodate the joists for this purpose.

A man was using the electric lift in a gas works to carry a truck of coke from the ground to the first floor. At the first floor, he opened the gates and wheeled the truck away. The gates, fitted with effective interlocks, were left open but because the brake was not in effective adjustment the lift moved clear of the landing. The man, on his return, wheeled his truck through the well gates ; he fell to the ground and was killed.

These accidents show the need for proper maintenance and inspection of lifting machinery. There should be a regular inspection of all lift suspension ropes, brake mechanisms, overrun trip gears, interlocks, and all mechanism on lifts and hoists ; if this were done there would be fewer lift accidents.

SLINGS AND SLINGING PRACTICE

Crane accidents in 1949 totalled 3768, of which 64 were fatal. Faulty slinging accounted for some 800, of which 13 were fatal. In a recent steelworks' accident a load consisting of 20 bundles of flat steel strip, each 65 in. long, was being moved by two labourers ; the load was lifted by an overhead electric gantry crane, its total weight being 23 cwt. Two endless three-strand sisal rope slings, each 11 ft. 3 in. long, were used, the diameter of which was about 1 in. One end of each sling was placed on the hook of the crane ; they were passed beneath the load and the other ends brought up and also placed on the hook. The load was lifted, moved about 6 ft. and lowered on to the platform of a weighing machine ; after weighing, it was again lifted by the crane. After travelling 5 ft. in the required direction, the load suddenly slipped out of the slings, and fell on a worker packing material nearby. The steel strip was oiled before dispatch to prevent corrosion during transit ; the rope slings were in good condition, although greasy from the oiled loads. There was no question of failure of the slings. The accident was caused by the unsafe and stupid method of slinging used, the open method. If the end of each sling had been passed round the load near the ends, passing it through the loop formed by the other and then over the crane hook, they would have tightened around the load when the lift was taken and held it securely.

Responsibility for this accident rested morally and legally with the management, who failed to supply adequate supervision, and permitted unsafe working. It is reasonable to assume that this was not the first time these men had slung bundles in this manner, and the foreman or supervisor should have corrected the practice at once.

There should be constant attention by managements to the safety education of men engaged on slinging processes and also generally to ensure good housekeeping throughout the works.

CHAIN SLINGS

Important points to be remembered in connection with the use of chain slings are :

(*a*) The effects of shock loading
(*b*) The variation of the safe working load which takes place in multiple-leg slings as the angle between the legs is altered.

Both these points may result in overloading. Shock loading occurs in a chain sling whenever the load speed is suddenly varied ; experiments show that the overload can be as much as five times the normal working load.

Steel chain, which is much stronger than wrought iron, is now manufactured in compliance with B.S. 590 (1949) for mild steel and B.S. 1663 (1950) for the

higher-tensile steel chain. The latter lays down breaking loads based on the formula $40d^2$ tons and allows a 33% higher safe working load than that in B.S. 590. There is a wide choice of steels available which make it possible to have a chain with properties most suited for the job in hand.

Certificate of Exemption No. 1, issued under Section 23(*f*) of the 1937 Factories Act, exempts steel chain from the requirements of periodic annealing, except for chains or slings of ½-in. dia. or smaller, or chain used with molten metal, where the requirements are every six months. The requirements of the Act regarding inspections and heat-treatment are the minimum requirements of good practice.

In connection with the use of steel chains:

(1) The safe working load of chains made to B.S. 1663 (1950) should be kept the same as for wrought iron and mild steel at $6d^2$, and the increased minimum breaking load of $40d^2$ used as an additional margin of safety. This is especially important when users have a mixture of wrought iron, mild steel, and higher-tensile steel chains in use in the same works. By keeping the safe working load of higher-tensile steel chain the same as that for wrought iron and mild steel, breaking loads of over seven times the safe working load can be obtained. The chains are proof-tested to the increased B.S. 1663 proof load, although only certified for the mild-steel and wrought-iron safe working load

(2) As a safety precaution, all multiple-leg slings should be marked for the safe working load at the working angle, and not for 0° as in current practice

(3) The responsibility for the care and storage of lifting tackle not in use should be vested in one person. A store should be provided in which to keep the tackle under cover, and its issue and receipt should be controlled

(4) Since shock loading can be up to five times the normal, great care should be taken to ensure careful slinging and lifting

(5) Chain safe working load charts as supplied by makers do not usually give figures for slings with more than two legs. Opinions as to the safe working load of three- or four-leg slings differ. Often when such slings are in use the complete load is carried by only two of the legs. In the interests of safety three- and four-leg slings should have the same safe working load as double-leg slings

(6) Steel chain slings should be normalized once every 12–18 months, depending on usage.

WIRE ROPE SLINGS

The usual structure of wire ropes, which is fairly flexible, solid, and has little stretch, is 6×19. For larger sizes 6×37 is to be preferred, but slings 6×24 are often used on account of their greater flexibility.

Inspection should be frequent and effective. Tallies or labels for marking the rope should be small to prevent foul in working, and the stamping should be easy to read. The tally must be easy to mark and to attach to the rope.

OVERHEAD TRAVELLING CRANES

Many accidents occur yearly with overhead travelling cranes, which are considered by a recent report on mechanical handling to be the basic mechanical handling equipment in steelworks. Increase in production speeds makes it essential for them to be in use constantly and at high pressure. The time available for overhaul is consequently limited and great demands are placed on those responsible for their maintenance.

During 1949, 46 accidents, including eight fatalities, resulted from contraventions of Section 24 (7) of the Factories Act, which details the precautions to be taken when men are working in places where they are liable to be struck by a crane; cranes must not be allowed to approach within 20 ft. of workplaces. It is difficult to enforce this sub-section owing to the weakness of the human element with one crane working on the track, and more so where a number of cranes operate on the same track.

Many of these accidents occur to maintenance men. At one steelworks where four men were painting a girder near the track of an overhead travelling crane, the contractor was warned by the works management, but the only precaution taken was for the foreman to shout when the crane approached. In one case one man took no notice, and was struck by the crane and killed. The responsibility for this accident rested with the works management as the occupiers and not with the contractors.

In a recent case in a large steelworks whose precautions in relation to Section 24 (7) are of a high standard, a contractor's workman was injured by an overhead travelling crane. He was inspecting work near the overhead crane track, and to do this he held the track with his hand. The crane driver did not see him and the gantry wheels ran over his hand and amputated his fingers.

In a recent accident a fitter and his mate were installing a pipe run near the track of an overhead gantry crane. When the men were working the crane driver was given a token card, and a red flag was placed 20 ft. from where they had to work. This system was faithfully carried out during the installation of the pipe run, but during the subsequent test the fitter asked his mate to go up to the crane track and open a valve near the track. The crane driver was not warned and as a result the man was struck by the crane and killed. Apart from the factor of the human element in this case, it shows the need, when planning new work, to avoid installing valves and similar gear near the tracks of overhead cranes.

The accidents quoted emphasize the need for an effective system to ensure compliance with Section 24 (7). In some works scotches are placed on the track at the statutory distance from the place where the men are working and the crane drivers are warned. There are obvious defects in this system, especially where the cranes travel at speed. Another method is to place large red flags on or near the track, and to warn the driver. In one large steelworks red oil lamps are suspended from the track on each side of the workplace, and a lookout man is placed in the driver's cabin, or where there is more than one crane, in the cabin of each crane on either side of the workplace. This system is expensive in manpower, but not as expensive as accidents.

Another way suggested is for each crane to be fitted with a ramp operating a cut-out switch, controlling the long-travel motor. Attached to each stanchion, on the appropriate side of the track, at ground level, are handles which operate strikers. When operated these strikers are raised and contact the ramp on the crane. The appropriate ramp is raised on each side of the workplace and the handle locked in position.

When a crane approaches the workplace it is stopped as soon as it strikes the ramp. The objection is that where fast-moving cranes are concerned, reliance has to be placed on the efficiency of the brakes ; it may be possible to include some scotching system in conjunction with the ramp. Another method is to place detonators on the track, but workpeople object to them, and it is possible in a noisy shop for their operation to pass unheeded.

To my mind, the use of red lamps and lookout men is the best, but whatever system is used strict enforcement is always necessary ; relaxation weakens the respect of the workmen for the system.

In 1949 there were 25 accidents, four fatal, from persons being trapped between the roof structure and some part of the bridge of overhead travelling cranes, or between the crab mechanism and some fixed part of the crane. A steelworks accident some years ago illustrates this type. A 140-ton ladle crane with a 10-ton auxiliary hoist was about 70 ft. above the floor, and the driver's cabin was suspended beneath the gantry 30 ft. below. Adjustment was necessary to the brake gear of the main crab cross-travel, and as soon as the crane was free the driver informed the fitter that he could carry out the adjustment. Before leaving the crane the driver placed the main isolating switch in the open position, normal procedure when leaving the cab ; the fitter placed a warning board on the isolator and then went to the gantry to adjust the brake. This board fell down, and later the driver returned to the crane to place a ladle beneath a tapping position. Seeing no notice, he closed the switch and operated the crane. At that moment the fitter's mate was passing the main travel motor on the inside and was crushed between the crab and the motor, receiving fatal injuries. This accident illustrates two points :

(*a*) Lack of consideration by crane manufacturers to safety for maintenance personnel at the design stage ; and

(*b*) A slipshod system of safety supervision by the occupiers.

In the case of (*a*) the makers provide an access catwalk on the gantry and then obstruct it with the main travel motor. They should ensure that the catwalk abutting the motor is wide enough for men to pass safely and not require them to climb over or around the motor. In the case of (*b*) there should be either a method of positively locking the isolator switch in the off position, or an isolator on the gantry catwalk operated by men working there. I favour the first alternative. Some years ago I worked in a large factory where all fitters and electricians responsible for the maintenance of overhead cranes, conveyors, etc., were supplied with small brass padlocks bearing their clock numbers. Before working on such plant, the fitter or electrician would lock the switch, and in addition hang an enamel warning sign on it ; they did not rely on a chalked board propped up on the switch. This locking system worked well, and is certainly preferable to the removal of the fuse bridges, the practice in many works. Removal of fuses introduces the possibility of their getting mixed up and the wrong fuses being replaced, as well as breakage of the bridges. An additional precaution when the operating crab is far removed from the bridge is the provision of some system of communication between the bridge and the driver so that instructions may be given during tests. A speaking tube between the bridge and cabin is a simple, cheap, and effective method of communication.

These descriptions of accidents should point the need for a safety survey of all overhead cranes to assess their accident potentialities. In a medium-sized works this might seem unnecessary, so I will mention one such hazard. Access to the driver's cabin in an overhead travelling crane was from the side. It was not considered practicable to fit the access ladders and platforms at each end of the shop, and so elevated platforms were provided in suitable positions over which the driver's cabin passed, the undersides of the cabs clearing the platforms by about 6 in. This seems a very dangerous practice : a driver of an overhead crane has his attention on his load and would not necessarily see someone climbing the iron ladder of the access platform ; should he approach when someone's head was above the level of the platform, that person would be injured.

All gearing accessible from workplaces should be securely guarded, as should the driving shaft and couplings for main travel, whether above the bridge, as is usual, or beneath, within the bridge structure. Safe access should be provided to both driver's cabin and bridge, and there should be an emergency system to enable the driver to leave his cab if necessary when the crane is not at the access platform ; he should not have to clamber out and along the track. Special escape gear can be obtained for this, but I prefer the ordinary rope ladder. The special escape gear which has a webbing harness on the end of a rope, and an automatic release and control mechanism, is satisfactory if properly inspected and maintained. As with all emergency equipment used only occasionally, the human element enters, and it is not wise to rely on such maintenance unless there is an unusually high order of safety supervision. It is better to choose the simplest emergency equipment ; this does not imply that the rope does not require inspection, but that it is less likely to go wrong than more complicated mechanisms.

Another common cause of accidents on overhead cranes is the falling of tools, left on the crane platform by maintenance men and later kicked over the edge. Toeboards of adequate height should be fitted to the edges of all crane platforms, and indeed to platforms of any type. In the Building Regulations, where the provision of toeboards is made a statutory requirement, the height is given as not less than 8 in.

In a recent accident in a Sheffield factory, a man was fatally injured through falling off the overhead crane platform on the crab side. I have never yet seen a guard rail on this side. A difficulty is the possibility of a man becoming trapped between the crab and the rail, but this could be overcome by attaching a wire rope to the crab carried over pulleys attached to a stanchion at each end of the platform. There would need to be some tensioning device but I cannot see any practical difficulty in adopting this method of guarding the inrunning edge of the platform.

JIB CRANES

In 1949 there were 47 accidents due to jib cranes overturning, 27 relating to mobile jib cranes as distinct from cranes operating on rail tracks. Too little attention is paid to the use of the safe working-load indicator, and, in the case of track cranes, to the condition of rail tracks. The Chief Inspector rightly calls attention to the need for extra care when using mobile jib cranes on sloping and uneven ground, which has a pronounced bearing on the safe working load of the crane ; if such conditions are not properly assessed the crane may overturn. It is important that the tracks of track cranes should be well maintained, and any slope borne in mind when operating the crane in relation to its safe working load. This applies to a greater degree with mobile trackless cranes.

HANDLING OF GOODS

The Annual Report of H.M. Inspector of Factories states :

> It is encouraging to see a drop in the number of accidents due to the handling of goods—but, unfortunately, this cause of accidents still maintains its high percentage of the total.

It was approximately 27·5%, *i.e.*, 55,000 accidents. Mention is made of two steelworks ; one, using hand or semi-mechanized methods, has more than double the handling accidents of the other which is on the strip processes. At the same time the former has only a quarter of the production of the latter, which emphasizes the advantages of mechanization in relation to handling from the safety as well as from the production angle.

The injuries sustained in handling accidents are usually minor ; there were, however, 13 fatalities. The causes are the handling of materials such as tinplate and sheet steel in the course of processing, and faulty stacking. We may include under this heading a large proportion of the accidents listed under the classification " stepping on or striking against objects " which in the 1949 Report totalled 13,000, with ten fatalities. Many handling accidents are due to congestion of workplaces by material in the course of processing, narrow workplaces, and the like.

Apart from a continuous and enlightened educational programme to train workpeople in safe methods of material handling and in tidy work habits, the most effective method of reducing the large total of accidents which annually arise from this cause, is increased mechanization and what safety officers call ' good housekeeping.' Apart from the question of safety, this is also good business. There have recently been great increases in productivity due to new machines and techniques, which have created great problems in connection with the even flow of material, particularly in older works with limited floor space.

The more important details of good housekeeping and handling are :

(a) *Handling, Storage, and Placing.* Satisfactory control of this requires careful consideration of all factors of tonnage and volume of material to be handled, the quantities required at successive steps of the process, allowance of the floor area necessary, and the methods to be used in handling and transporting the materials and articles. There should be no unnecessary handling, and materials should be delivered when and where they are wanted in the right quantities to avoid bottlenecks in production.

(b) *Methods of Stacking.* These must be worked out for each class of material or articles. For example :

> (1) Height of stack, dependent on the nature of the material and consequent danger of toppling, the means used for stacking and the flow of adjacent traffic. Another point with a bearing on this problem is possible interference with fire precautions
>
> (2) Strength of support, especially if above ground-floor level. In such cases it is advisable to have the safe floor loads posted up
>
> (3) Evenness of support and its continued stability, particularly necessary for yard stacking where moisture may cause the ground to yield and cause toppling
>
> (4) Location. Aisle traffic in the presence of work-benches may limit the height or nature of material to be stacked in otherwise suitable areas
>
> (5) Stacking of small components, often done with bins or wheeled containers in which the articles are collected from machine or workbench. A system of ' palletization ' is an effective answer
>
> (6) Pipe, or other long stock. Suitable racks greatly improve handling of this type of material. Projecting ends should be protected by location or effective fencing
>
> (7) The use of manual methods instead of some form of stacking hoist or conveyor is a very common fault in this country. Progressive management must continually seek better and safer methods of stacking and incidental handling.

To ensure that machine operators are not distracted from their proper function of operating their machines, the materials required for the processing should be delivered ready for their next operation so as to avoid rehandling. Picking up and placing down should be reduced to a minimum.

The use of some form of palletization reduces congestion in workplaces and walkways, improving safety and production. The use of the fork truck with pallets is one of the most important developments in material handling, but their general use in this country is comparatively recent. They enable works managers to make greater use of the third dimension, and to think in terms of cubic feet rather than of square feet when considering storage.

Another useful method of handling and storage is the unit conveyor system. This means the absence of workbins adjacent to the machines and in the walkways. The floor of the shop is completely free of stacking, and only carries the machine and operator. Overhead conveyors dip to the machines and work-benches, practically bringing the material to the operator's hand. The conveyor systems are designed to deliver the articles more quickly than the work-people require them, and in that way a store is built up, literally in the air. The overhead system stores the requirements of a full shift, and builds up a useful reserve, enabling the floors to be kept clear.

The old method of scrap and waste disposal is to let the floor catch the waste and then employ labour to clean it up. Good management estimates probable waste in advance and provides suitable means of collecting it as it is produced. An intelligent interest in keeping waste and scrap down helps both safety and profits. Scrap can be removed by conveyor to a central collecting station.

Clear marking of aisles and of spaces reserved for storage is essential for safety, and there should be strict observance of the rule prohibiting the placing of materials in aisle spaces. The width and layout of aisles and roadways vary with the nature of the traffic. For walkways it is well to establish 36 in. as a minimum wherever practicable. Where there is considerable powered traffic they should be 3 ft. wider than twice the width of the trucks used. Excessively narrow aisles are a common fault: aisles too narrow for safety are also too narrow for efficiency.

Projecting nails are a severe handling hazard. Nails left projecting when kegs, barrels, or boxes are opened invite injury, as do nails in planks or boards. Nail punctures are particularly likely to become infected with germs. When barrels or cases are opened the nails should be drawn or bent over and the points hammered into the wood.

The danger of projecting nails would seem too obvious to mention, but it strikes the keynote of the fundamental truth of accident prevention, a truth which must be repeated over and over again—it is more often the simple and obvious things that cause accidents.

CONCLUSION

It is essential to grasp the vital importance of the near accident, of the narrow escape, of the slight-injury accident. If we find out about these and guard against their repetition, we have more than half won the battle of safety for the industrial worker. Most accidents are caused by the neglect of some small elementary precaution, or by one small unsafe practice, which one can often get away with, but which one day leads to disaster. Accidents are rarely caused by some major unforeseeable breakage or explosion; they mostly arrive through neglect of small everyday things which can be put right; responsiveness to the opportunity presented by the near accident can and should always result in the unsafe practice being stopped or remedied before an injury accident occurs.

Safety education and the application of common-sense to everyday activities are the surest ways of obtaining a substantial reduction in the severity and number of accidents.

DISCUSSION

Mr. **A. Taylor** (Chief Safety Engineer, Richard Thomas and Baldwins, Ltd.) read his paper on "The Prevention of Handling and Lifting Hazards."

Mr. **G. Satow** (Stewarts and Lloyds, Ltd.): There is a great need for education and training in accident prevention; putting up more notices and more guards will not achieve the objective in view.

Preventive measures can be reduced by introducing and practising safe methods of working, which involves care in the selection of personnel and consideration of the suitability of individuals for their particular tasks. There are many practical difficulties associated with doing this. It is right in principle, but as far as I know no firm has satisfactorily solved the problem. Men carefully selected for one job as being suitable in temperament do sometimes change their job.

I agree that most injuries could be avoided by the application of a proper lifting technique, or by the exercise of a little extra thought, but how are we going to get people to think and exercise common sense?

In the steel industry, we have only scratched the surface of proper training in accident prevention, and we have never looked at the problem as a whole, which involves the training not only of workpeople and supervisors, but also of assistant managers, managers, general managers, directors, and managing directors.

The responsibility for accident prevention rests with the management, and it is the job of the staff executives, the training officer, and the accident prevention officer to carry out the policy laid down. There are many cases in which this has not been done.

In the programme for their Annual Conference at Ashorne Hill this year, the Training Committee of the Federation has already included the subject of accident prevention. A film will shortly be available to serve as an introduction to a series of film strips and lecture notes, each dealing with specific risks. These are practical means of assisting training officers and accident prevention officers.

It may be that the Training Committee will wish to examine the means and methods of training on a broader basis, collaborating with the Area Training Committees to secure speedy and effective results.

Mr. **A. Taylor**: Safety education should be part of the curriculum of schools, particularly those in industrial areas, and should be continued in the workshops. It should not begin and end with seeing the Safety Officer before starting work. Newcomers into industry should receive training in safety when they enter the works, and there should be refresher courses at certain intervals. Such a scheme is under consideration by the company with which I am associated. It is a long-term programme, and will not give quick results. It will mean hard work, but it is worth trying to achieve.

Mr. **H. Eccles** (Senior Engineering Inspector of Factories): Mr. Taylor dealt with the economics of accident causation, quoting figures which ought to influence the hard-headed business man to greater effort. But we must not forget the humanitarian side, that is, the type of accident which not only costs money but kills or makes a cripple of the victim.

With this in view, I would direct attention to accidents arising from the use of plant. Of the 96,000 accidents which Mr. Taylor quoted, only 4389 were due to power lifting machinery but, from this single cause, 94 deaths occurred, *i.e.*, one-fifth of the total fatal accidents in factories. Nearly a quarter of these power-lifting-machinery accidents occurred in iron and steel works.

No accident prevention activity yields such high dividends as safe plant, properly maintained and used in a properly organized and controlled manner. Hoists and lifts are an example of what can be achieved in making machinery safe. The Factories Act, 1937, might be called 'the hoists and lifts charter,' for it introduced a rigid system of inspection and made certain automatic safeguards statutorily compulsory. Until then, hoist accidents were common, and in 1937 432 accidents, with 29 fatalities, occurred. Since then, the number has fallen steadily until in 1949 the total was only 102, of which five were fatal.

This example should stimulate industry in its effort

to deal effectively with some recurring ' black spots ' in accident causation tables. The Chief Inspector's Annual Report shows that 11 persons were killed and 55 injured owing to firms failing to comply with the requirements of Section 24(7) of the Factories Act. An alternative to the methods mentioned by Mr. Taylor is the provision of a signalman in a safe place, *e.g.*, on the ground, charged solely with warning the crane driver by sound signals before he comes within 20 ft. of the place where men are at work. Whatever system is adopted, it must be rigidly enforced, for only thus can accidents be prevented. The system of permit-to-work prevents many of these accidents. There should be a rigid system whereby no one is allowed in a place where he might be struck by a travelling crane without a permit to work there.

Mr. Taylor's suggestion for preventing falls from the bridge platform on the crab side is similar to an arrangement which I have seen for preventing trapping between the bogie and the tail of a slewing crane. A wire rope, extending the length of the bogie and weighted to keep it taut, passes round pulleys mounted on the end of the tail. As the crane slews the rope extends across the space in the angle between the tail and the bogie and acts as a barrier.

During the investigation of a serious case of overturning of a mobile crane, a witness said that on the many other occasions when the crane had overturned, without involving injury, it had simply been righted and put back to work. The factory management had not been aware that the overturning of a crane had to be reported to the Factory Inspector, whether personal injury was caused or not, and so the overturnings continued without action being taken to ascertain and eliminate the cause until someone was seriously injured. If they had been investigated in the earlier stages, the conditions giving rise to the overturnings would have been prevented.

In steelworks, certain cranes, especially jib cranes, are often called upon to handle loads of which the weight cannot readily be ascertained, as in slag handling, where the load may vary considerably, according to the metal content. The fitting of automatic safe-load indicators on such cranes is advisable so that the driver may know, irrespective of the nature and volume of the load, whether it is within the safe capacity of his crane.

A Committee set up by the iron and steel industry recently produced a specification for heavy-duty electric overhead travelling cranes for iron and steel works, which deals with every aspect of crane design from the production and the safety angles. Of special interest are the clauses ensuring safe access, ease of control and good visibility, effective lighting, good ventilation and temperature control within the cab, a proper seat for the driver, warning lights to safeguard against collision, and the provision of fire extinguishers.

Wrought-iron and mild-steel chains are comparable in strength, but with the former care should be taken to secure good quality puddled wrought iron. Two qualities, ' standard ' and ' special,' are provided for in British Standards, in which the manganese content is strictly controlled : that for special quality wrought-iron chain must be less than 0·075%. For the special quality chain a higher minimum breaking load and greater elongation are specified. The maker's test certificate has to specify the type of heat-treatment to which mild-steel chain has been subjected in manufacture. Higher-tensile steel chain is about one-third stronger than wrought-iron or mild-steel chain. If in a works where higher-tensile chain is used there are also wrought-iron or mild-steel chains, grave risk of overloading arises unless the safe working load of the higher-tensile chain is set no higher than for the ordinary chain. The higher-tensile chain has special markings, every twentieth link being marked, but there can be no assurance that a slinger will look at the markings. Makers are required, on test certificates for higher-tensile steel chain, to give details of the heat-treatment to which it has been subjected in the course of manufacture.

It is usual in iron and steel works, especially where hot metal is handled, to work to a safe working load based on $3 \cdot 5d^2$ tons, instead of $6d^2$ tons, as recommended for normal usage of wrought-iron and mild-steel chains. Where it is desired to take advantage of the greater strength of higher-tensile steel chain, and confusion with mild-steel or wrought-iron chain is not likely to arise, the appropriate safe working load for the higher-tensile steel chain on the same basis is $4\frac{2}{3}d^2$ tons.

Thimbles should be fitted in the eyes of wire-rope slings ; B.S. 1290 which deals with their design and use does not recognize plain loops without any reinforcement.

Plates without holes are commonly handled by cranes with plate clamps. These depend on friction, and are less reliable than tackle which is shackled or hooked on to the load, and so great care should be taken in their use. The gripping clamp should always be attached squarely to the plate. Works with competent design and supervisory staffs may be able to produce a satisfactory plate-clamp, but where such staffs are either not employed or their abilities not effectively utilized, home-made clamps often prove dangerous. Clamps should be obtained from competent manufacturers, care exercised in their application, and steps taken to secure proper maintenance.

The same applies to crane tongs used on combined gripping and stripping machines used for manipulating hot billets and ingot moulds. Maintenance is very important ; wear or distortion of the bits or ' spuds ' on the sides of the tongs may cause a dangerous type of load to slip or fall.

The substitution of mechanical for manual handling should reduce the frequency of accidents, but it is liable to increase their severity unless makers design generally to ensure safe working. Users must likewise, by frequent and efficient inspection and maintenance, by insistence on safe practices, and by effective supervision, avail themselves of the more effective control possible over the behaviour of a machine than of a human being.

The drivers of furnace chargers generally stop them by plugging, *i.e.*, instead of using brakes they momentarily put the controller in reverse direction, reversing the torque of the motor to pull the machine up quickly. A magnetic brake interferes with this and brakes are usually never fitted, or, if they are, are deliberately put out of action. Should the power fail when such a charger is in motion, the driver will be unable to stop it by plugging, and anyone in the way will be injured. The provision of an audible warning on these machines is essential, but means should also be provided to enable the driver to control them under all conditions. Drivers may resist the installation of a brake such as the electro-mechanical, which automatically comes into operation as the control handle passes through the neutral position, and so it may be more practical to use a magnetic brake independent of the controller which operates only if an emergency push is depressed or the main power supply fails.

Mr. **R. Murison** (Appleby-Frodingham Steel Co.) : I have just returned from a tour of American and Australian steelworks with one of my colleagues. We were impressed by the American sincerity regarding safety and also by their results. The national average frequency rate for iron and steel works for 1951 was less

than 0·5, compared with 3·26 for this country. In a steelworks of 5000 workers, the frequency rate of 3·26 would mean probably about 400 lost-time accidents per annum, but in an American works of the same size, the lost-time accidents for the whole year are as low as 33.

We have slightly different conditions in this country, and it has been said that the American statistics are artificial when compared with British figures, but no amount of artificiality on our part can suppress 200 or 300 accidents per annum, so we should not think that the American practice is no better than ours. Their practice and the results obtained are very good.

They have reached a state of education among supervisors, *i.e.*, managers, assistant managers, and foremen, such that they accept full responsibility for all accidents to the workers under their supervision. They are responsible for the safety of their departments ; the safety department simply guides and suggests. The responsibility for safety in a department lies with the supervisors, mainly the foremen. They also accept responsibility for accidents resulting from failure due to the human element, on the ground that these are due to lack of proper instruction and education by themselves and are not the fault of the workers. They argue that laxity on the part of the supervisors allows such accidents to happen.

Safety is discussed daily in some American steelworks, and is regarded as an important tool of management. Accident prevention is the first item on the agenda of the superintendent's daily production meeting. There are also general safety meetings held weekly or monthly.

One American method of applying safety discipline is insistence on strict adherence to safety regulations as published in pocket-sized rule books. These are sectionalized for the departments, since it is considered that there are certain rules which are more important to one department than to another ; they are issued to each employee, and a detachable back page is signed as a guarantee of receipt ; the employee then has no excuse for not being familiar with the safety regulations of the works. One of our difficulties in this country is in the enforcement of such rules ; there are flagrant violations daily. In America a record of violations of the safety rules is kept ; the recording of the violations is done openly by the foreman drawing the worker's attention to his failure to observe the rules, and the worker is given instruction on safety. This is followed by an 'unsafe practices report' being submitted to the employment department, where it is filed with the man's personal record. In the iron and steel industry where promotion is dependent on a ladder system, this can be a useful weapon in the hands of those in authority, as consideration is given to these reports when deciding promotion to higher grades.

This practice might well be adopted in this country ; it would be unlikely to disturb our present labour relations. It is one of the main features of the American accident prevention system, universally followed throughout.

The Americans in general have no difficulty in persuading employees to use protective clothing, such as plastic helmets, goggles, and safety footwear. The American is not troubled by inhibitions about his personal appearance, and the inhibitions in this country—the ridicule, the sense of making a spectacle of oneself—could be overcome by a campaign throughout the whole country for the greater use of special wearing apparel, particularly in iron and steel works. In America all the workers in the yards, the open hearths, and similar situations wear safety helmets. The machine-tool operators and foundry workers, exposed to flying particles, wear goggles, and even visitors must wear them. The wearing of special clothing is not generally made a condition of employment ; they rely on selling the idea to the worker. In dangerous situations, such as the melting shop, or the casting pit, the superintendent may forbid workers to enter without protective clothing ; this is for superintendents to decide, and not the safety department. All these points of American practice could be applied with advantage in this country.

There is in Australian practice a tangible incentive scheme in operation in certain steelworks. Target settings are established for small departmental groups depending on past accident experience, and a bonus is paid to each member of the group for an accident-free record for the target period. The bonuses are in kind, comprising articles such as shaving sticks, ash trays, and pencils. In a works with a population of 6000, this scheme costs about £2000 a year, but, since its adoption, it has reduced lost-time accident rates considerably. Is there any such scheme in use in this country ?

Mr. **A. Taylor** : We cannot compare our frequency rates with those in America, since the format is different.

Safety education must start at the top and work down, because we cannot expect the worker to take an interest in safety if the management do not do so. The management should always attend meetings of the Safety Committee if possible and not send deputies.

I am anxious that safety booklets should be issued. In some sections of the organization with which I am associated they are not issued because of the objections of shop stewards, who think that it might affect claims at common law in the event of accidents. To my mind, this is wrong.

I do not know of any incentive scheme in this country.

Mr. **J. Sanders** (Richard Thomas and Baldwins, Ltd.) : In manual handling of goods, fractures and sprains take priority in the smaller accidents, sometimes causing long periods away from work.

I have heard doctors say that diet plays a large part in fractures and sprains. Some years ago, if a person got a knock he would not lose time from work and would merely suffer from a nasty bruise, but nowadays after treatment he is reported to have a fracture and is in a plaster cast for some weeks. Some of these injuries, particularly where sepsis develops, seem to show decreasing chances of speedy recovery.

Many of the sprains reported as having been caused by lifting are often really caused by a lack of understanding of the human body, weather conditions playing no small part.

It would be useful if the medical side of the Factory Inspectorate could give some guidance in regard to the increasing number of accidents that occur in the handling of goods.

Mr. **J. MacColl** (H.M. Superintending Inspector of Factories) : In two recent cases in different works the thread of an ordinary crane hook stripped and the hook was let down. In each case, at the last two or three periodic examinations, the nut had not been removed. There had been no real examination but just an external inspection, in both cases by outside people. Is that type of hook right for carrying a ladle of steel ?

Consider, again, a steel ladle of the 'Jumbo' type with mandrels for lifting, the mandrel on each side having a flanged end so that the hook does not slip off. We have found in several different works that the hook can be placed on the flange and can slip off. It should not be possible for a man to place the hook on the flange.

These things involve education, training, safety precautions, and the use of the right tools for the job. Do we try to sort out what is wanting ? Is the training wrong ? Do the engineers and the works managers let

men do these things ? All these elements are involved in most problems.

Mr. **A. Taylor** : In regard to the first point, it is obvious that the last two or three periodic examinations had not been thorough. Effective crane inspection should have included an inspection of the hook and its retaining nut, which, after all, is one of the essential components of the crane.

The ladle mandrels should be designed so as to reduce the possibility of the hook being placed on the flange instead of in the groove. It is usual for the beam to be constructed so that the hooks naturally fall into the appropriate grooves. It would, however, be quite easy for the flange to be designed with a tapered periphery.

With regard to the question of education, and supervision by engineers and works managers, I would again refer to the 1 : 29 : 300 ratio ; there is no doubt that there is room for considerable improvement in the standard of safety education and supervision in industry.

Mr. **A. Bartholomew** (Park Gate Iron and Steel Co., Ltd.) : Rope escape ladders are liable to rot. A better type is the light steel-chain ladder with steel rungs.

To prevent falls from the platform on the crab side of an existing overhead crane, a wire rope could be attached to a support at each end of the platform, preferably with a support in the middle. Where there is little space in which to install a wire rope alongside the cross-traverse track, it can be done by a system of pulleys, as suggested by Mr. Taylor, although this may introduce other hazards.

Mr. **A. E. Moore** (Richard Thomas and Baldwins, Ltd.) : To deal with accidents due to faulty slinging, manufacturers of machinery and foundries producing very heavy castings should mark clearly the place where slings should be put upon the machine or casting. The slinger would then know where to place his slings without lifting the load two or three times to find a correct point of balance.

Manufacturers of machinery should also mark clearly the load tonnage of a piece of machinery. The same would apply to very large castings or bulky pieces of machinery leaving the ordinary machine shop. The slingers would not then have to guess the weight, and could choose the sling applicable to the load.

Manufacturers could also encourage their designers to incorporate a lifting lug in their designs. If this were done, the slinger would be able to put the sling directly on the lug.

Mr. **P. Jump** (N. Hingley and Sons) : There is no product which is so generally maltreated in many ways in an engineering or iron and steel works as a chain. To remedy this, many works conduct talks on the proper use of chains, proper slinging, proper material, proper records in the stores, and the sequence of life of the chains before they are retreated, retested, and re-certified.

There is no reference in the paper to wrought-iron chain. During the last few years high-tensile chain has been developed under B.S. 1663, but is it desirable to have high-tensile material, and if so, is it satisfactory that its strength should depend to a large extent on heat-treatment ? During service, repairs may have to be done, and odd links or odd hooks may have to be added. The smith cannot do that so readily with the heat-treated chain, and may easily destroy the initial value of that chain. Time has proved that the wrought-iron chain cannot be ignored ; 90% of existing lifting gear for important work is made from wrought iron, which is a highly ductile material, shock-resisting, and less subject to corrosion than mild steels. A chain may be dropped and notches put in the links. With a steel chain there is a danger of the propagation of cracks, whereas with wrought-iron chain, as a result of its process of manufacture, this is much reduced.

Mr. **A. Taylor** : The high-tensile steel chain gets over the difficulty in many works of the absence of properly supervised heat-treatment of the wrought-iron chains, which are liable to become mixed and do not always get their heat-treatment and annealing at the proper time. With the steel chain this risk can be avoided. They do require normalizing, but they are the safer to use.

The **Chairman** : This meeting was called for the specific purpose of increasing interest in accident prevention. I hope it has encouraged what is being done already and has acted as a stimulant for further work on this subject.

The Committee are delighted to have this large attendance and to receive such support for the meeting.

I thank the various speakers who have taken part in the discussions and also the Institution of Electrical Engineers for making this excellent accommodation available to us.

IRON AND STEEL ENGINEERS GROUP

Engineering Committee 1952–53

The following Members have been appointed to serve on the Engineering Committee :

	Chairman
C. H. T. Williams	Park Gate Iron and Steel Co., Ltd.
	Members
J. Baker	Joseph Booth and Brothers, Ltd.
W. W. Franklin	Davy and United Engineering Co., Ltd.
J. L. Gaskell	Appleby-Frodingham Steel Co., Ltd.
T. A. Hogarth	Llanelly Steel Co. (1907) Ltd.
W. A. Johnson	United Steel Companies, Ltd.
W. M. Larke	Stewarts and Lloyds, Ltd., Bilston.
P. A. Lee	Arthur Lee and Sons, Ltd.
G. S. Martin	Lanarkshire Steel Co., Ltd.
J. E. Owston	F. B. Engineers, Ltd.
E. Pinches	Richard Thomas and Baldwins, Ltd.
W. J. Pool	British Thomson-Houston Co., Ltd.
I. S. Scott-Maxwell	Steel Company of Wales, Ltd.
A. Taylor	Cargo Fleet and South Durham Iron and Steel Co.
W. Udall	Brightside Foundry and Engineering Co., Ltd.
W. S. Walker	Round Oak Steelworks, Ltd.
C. H. Williams	Stein and Atkinson, Ltd.
R. L. Willott	John Summers and Sons, Ltd.
	Ex-Officio
Capt. H. Leighton Davies	President, The Iron and Steel Institute
J. Mitchell, C.B.E.	Hon. Treasurer, The Iron and Steel Institute
H. H. Mardon	British Iron and Steel Research Association.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Meeting in Swansea

A Special Meeting of the Institute will be held in Swansea from **7th to 10th October, 1952.** By invitation of Mr. E. H. Lever, Chairman of the Steel Company of Wales, Ltd., a visit will be made to the Trostre works of the Company on the first day, the Minister of Supply being the chief guest. The remaining programme will include visits to other works of interest in South Wales, and special arrangements will be made for Ladies.

Autumn General Meeting, 1952

The **Autumn General Meeting** will be held in London on Wednesday and Thursday, **26th and 27th November, 1952.**

Andrew Carnegie Research Fund

Mr. B. CINA (Sheffield University) has been awarded a second grant from the Fund to aid his research on the effect of cold work on the gamma–alpha transformation characteristics of three Fe–Ni–Cr steels.

Special Report on the All-Basic Open-Hearth Furnace

The latest addition to the series of Special Reports published by the Institute is a report on "*The All-Basic Open-Hearth Furnace*," prepared by a joint sub-committee of the British Ceramic Research Association and the British Iron and Steel Research Association. The papers were presented at the 36th Steelmaking Conference at Ashorne Hill in May, 1951, and a report of the discussion at the Conference is included.

The All-Basic Open-Hearth Sub-Committee was formed, shortly after the war ended, to promote research on and development of the all-basic furnace, and as a result of preliminary study six furnaces of varying design were constructed, five in Great Britain and one in Holland.

Very full details of the experiments made on these furnaces, together with observations of their performance, are presented in Part III, in what is considered to be the most suitable form for study and comparison of results; it is hoped that this will constitute in the future a standard method of recording information. The potentialities for further research and development are considered to be very great, and the Report suggests the lines along which future investigation should be carried out, if the all-basic furnace is to become an economic proposition. Great stress is laid on the need for the development of an improved and cheaper basic brick, and for better aerodynamic and mechanical design.

The Report, No. 46 in the Series, is amply illustrated with diagrams and photographs, and is bound in cloth with stiff board covers; it can be obtained from the Offices of the Institute at 25*s.* per copy, post free (15*s.* to Members).

NEWS OF MEMBERS

▶ Mr. R. G. BHATAWADEKAR, metallurgist with the Ministry of Railways, Central Standards Office, New Delhi, has been posted to Chittaranjan, West Bengal.

▶ Mr. P. CLARK, of the Anglo-Iranian Oil Company, Ltd., has left England to serve as Corrosion Engineer to the Company in Kuwait until January, 1953.

▶ Mr. E. LL. EVANS has left the National Physical Laboratory to join the Corrosion Group of the Chemical Research Laboratory of D.S.I.R., Teddington, as a Senior Scientific Officer.

▶ Mr. P. GREGORY has left the Royal Aircraft Establishment, Farnborough, to join the British Non-Ferrous Metals Research Association, London.

▶ Mr. K. HOSELITZ has left the Permanent Magnet Association, Sheffield, to take up an appointment at the Mullard Electronic Research Laboratories, Redhill, Surrey.

▶ Mr. J. S. JACKSON has left C.A.V. Ltd., Acton, to take up an appointment with the British Thomson-Houston Co., Ltd., Rugby.

▶ Mr. A. C. JESPER has left Leeds University and has taken up an appointment with Rolls-Royce, Ltd., Derby.

▶ Mr. E. E. KUGEL, of Hydropress, Inc., New York, has been appointed Director of Sales for the Loewy Rolling Mill Division of the Company.

▶ Mr. I. S. SCOTT MAXWELL has left the British Iron and Steel Federation to join the Steel Company of Wales, Ltd., Port Talbot.

▶ Mr. M. C. NICKSON has left Mond Nickel Co., Ltd., Birmingham, to take up an appointment as Chief Metallurgist with G. A. Harvey and Co. (London) Ltd.

▶ Professor A. M. PORTEVIN, an Honorary Member of The Iron and Steel Institute, has been elected a foreign Member of the Royal Society.

▶ Mr. S. T. ROBSON has resigned from the Boards of Head, Wrightson and Co., Ltd., and Head Wrightson Processes, Ltd.

▶ Mr. A. J. SHALER, Scientific Liaison Officer, U.S. Embassy, London, has returned to Massachusetts, U.S.A.

▶ Mr. A. STEPHENSON has left the Monotype Corporation, Ltd., to take up an appointment with the Ministry of Supply, Millbank, London, S.W.1.

▶ Mr. G. A. WHITTAKER has left Head Wrightson Stampings, Ltd., to join Rolls-Royce, Ltd., Crewe.

▶ Mr. D. H. WILLEY has left the Ministry of Defence to take up an appointment with the B.S.A. Group Research Centre, Sheffield.

▶ Mr. R. W. WILSON has left the Physical Chemistry Department of Cambridge University to join the Thornton Research Centre of the Shell Petroleum Co., Ltd., Chester.

▶ Mr. J. WINTON has left Leeds University and has joined the research staff of the Association of Electrical Industries, Aldermaston, Berks.

Birthday Honours

▶ Mr. GEOFFREY SUMMERS, C.B.E., D.L., Director of John Summers and Sons, Ltd., and other companies, has been made a Baronet.

▶ Dr. H. SUTTON, Director of Materials Research and Development (Air), Ministry of Supply, has received the C.B.E.

▶ Dr. R. HIGGINS, Assistant Professor of Metallurgy, University College, Swansea, has received the O.B.E.

Obituary

Monsieur ALOYSE MEYER, President of the Conseil d'Administration of the Société Anonyme des Aciéries Réunies de Burbach-Eich-Dudelange, at Luxembourg on 3rd May, 1952.

M. Meyer, who was 68, was President of the Chamber of Commerce of the Grand Duchy of Luxembourg, and a Member of the Executive Committee of the International Chamber of Commerce. He became a member of The Iron and Steel Institute in 1921 and was elected an Honorary Vice-President in 1934. He was awarded the Bessemer Medal in 1937.

Mr. WILLIAM WALLACE SCOTT, Jr., Vice-President of the Laclede Steel Company, St. Louis, Missouri, U.S.A., on 15th April, 1952.

CONTRIBUTORS TO THE JOURNAL

C. E. Homer, B.Sc., Ph.D., F.I.M.—Superintendent, Metallurgical Research, at the Department of Development and Research, Tube Investments, Ltd., Birmingham.

Dr. Homer was educated at Sebright School, near Kidderminster, and at the University of Birmingham, where he graduated with 1st class Honours in Metallurgy in 1931. He was then awarded a Carnegie Scholarship by The Iron and Steel Institute, and carried out a programme of research at Birmingham University on behalf of the Corrosion Committee of the Institute. He obtained the degree of Ph.D. with a thesis based on this work. On leaving the University he joined the staff of the International Tin Research and Development Council, London, serving first as Information Officer and later as Research Officer and Technical Development Officer. He left early in 1942 to become Chief Metallurgist at the Castle Bromwich Works of Vickers-Armstrong, Ltd., (Aircraft Section), and held this appointment until 1945, when he became Chief Metallurgist of Darwins, Ltd., Sheffield. He took up his present appointment in 1946.

B. Cina

F. A. Hodierne ⟶

Dr. Homer was a Member of Council of the Institution of Metallurgists from 1946 to 1951, and served on the Council of the Birmingham Metallurgical Society from 1948 to 1952.

B. Cina, B.Sc., D.R.T.C.—Research Metallurgist at the Brown-Firth Research Laboratories, Sheffield. Mr. Cina was born in 1926 at Glasgow, and was educated at Queen's Park Secondary School and at Glasgow University and the Royal Technical College. He graduated with the degree of B.Sc.(Hons.) in 1945. He was first employed at the Clydebridge Steel Works Research Department of Colvilles Ltd., where he worked on the problems of slag control and ingot cracking. He joined the Brown-Firth Research Laboratories in 1947, where he specialized on the metallographic aspects of high-alloy steel research. Mr. Cina is a research student in the Metallurgy Department of Sheffield University, and has received an Andrew Carnegie Research Grant.

F. A. Hodierne, B.Sc., A.I.M.—Metallurgist with the Department of Development and Research, Tube Investments, Ltd. Mr. Hodierne was born in 1923; he was educated at Coventry Technical College and at University College, Nottingham, and graduated in 1945. During the war he was with Alvis (Aero Engines) Ltd., at Coventry and at Mountsorrel, Leicestershire. In 1946 he joined Tube Investments Ltd., where he has been mainly engaged in research on stainless steel tube production.

THE IRON AND STEEL ENGINEERS GROUP

The **Nineteenth Meeting** of the Group will be held in London on Wednesday, 15th October, 1952. Two papers will be presented for discussion: "Electric Drives for Continuous Hot Mills," by G. R. Wilson (English Electric Co., Ltd.), and "A New Continuous Hot Mill for Strips up to 24 in. Wide," by M. Langen (Loewy Engineering Co., Ltd.).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Annual Report of Council, 1951

The Council of the British Iron and Steel Research Association has presented its Eighth Annual Report for the year ended December 31st, 1951.

The Report reflects the need to conserve scarce materials and to make the best use of available resources. Results of research show opportunities for such economies, and for improvements in efficiency of manufacture and in the quality of the industry's products. The Association has already applied many of these economies and improvements, and brief descriptions of the work of each of its Divisions and Departments are given, with a list of the reports issued during the year.

New contracts with other research associations have been made, thereby avoiding the overlap and duplication of research investigations and providing a reciprocal exchange of information that is most valuable.

In Holland and Belgium, the Association is engaged in two international projects to determine the minimum sizes of ore fines and low-grade fuels that can be smelted without agglomeration.

The research programme, which has expanded during 1951 as a result of the acquisition of more laboratory accommodation, is likely to be maintained at the present level during 1952; and by the end of the year, when the Sheffield laboratories will be nearly complete, the industry will possess a Research Association well equipped for the urgent problems confronting it.

AFFILIATED LOCAL SOCIETIES

Leeds Metallurgical Society

The following meetings have been arranged:

1952

2nd Oct.—Presidential Address.

6th Nov.—"*The Production of Some of the Rarer Metals*," by A. R. Powell.

4th Dec.—"*Delayed Fracture in Metals Under Static Load*," by P. Stables.

1953

8th Jan.—Film Night.

5th Feb.—"*The Continuous Casting Processes*," by E. Scheuer.

5th Mar.—"*Lubrication in Cold-Working Processes*," by A. E. McAulay.

2nd Apr.—"*Recent Advances in Electro-Deposition of Metals and Alloys*," by J. W. Cuthbertson.

7th May—Annual General Meeting and Junior Member Papers.

North Wales Metallurgical Society

The list of officers for the session 1952–53 is as follows:

Chairman

E. TAYLOR-AUSTIN

Vice-Chairman	Treasurer
R. L. WILLOTT	S. ANDREW
Secretary	**Asst. Secretary**
S. WEIR	J. BEVIS EDWARDS

Committee

C. H. BACON	C. LEWIS
H. EDWARDS	A. D. OSBORNE
M. HALL	J. T. SCOTT
H. H. JOHNSON	J. TILL

NEWS OF SCIENCE AND INDUSTRY

Cambridge Summer School in Automatic Computing, 1952

A Summer School in programme design for automatic digital computing machines will be held in the University Mathematical Laboratory at Cambridge from 16th to 26th September, 1952. Further particulars may be obtained from G. F. Hickson, M.A., Secretary to the Board of Extra-Mural Studies, Stuart House, Cambridge.

Symposium on Mineral Dressing

A Symposium on Mineral Dressing is to be held by the Council of the Institution of Mining and Metallurgy from 23rd to 25th September, 1952, at the Imperial College of Science and Technology, (Royal School of Mines), Prince Consort Road, South Kensington, London, S.W.7.

The purpose of the Symposium is to discuss recent advances in the field of mineral dressing. Over 30 short papers, dealing with fundamental concepts and experimental methods, advances in practice at selected plants, and advances in plant design and machine manufacture, will form the basis for the discussion, and will be available before the meeting. A charge of about £2 (£1 for members of the Institution) will be made to cover attendance, a set of proofs of the papers, and a copy of the final volume of the Proceedings.

Visits to plants and research laboratories will be arranged for a few days following the meeting.

The Symposium is open to all interested persons, whether or not they are members of the Institution. Further details may be obtained from the Secretary, Institution of Mining and Metallurgy, Salisbury House, Finsbury Circus, London, E.C.2.

Beilby Memorial Awards, 1951

The Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry, and the Society of Chemical Industry, have decided to make two awards, each of one hundred guineas, from the Fund for 1951. These awards have been made to :

KENNETH HENDERSON JACK, M.Sc. (Dunelm.), Ph.D. (Cantab.), F.R.I.C., in recognition of his experimental contributions to the study of interstitial alloys, especially in the iron–nitrogen and iron–carbide–nitrogen systems.

WILLIAM ARNOLD WOOD, D.Sc. (Manchester), F.Inst.P., in recognition of his experimental contributions to knowledge of the mechanism of deformation of metals.

Awards from the fund are made to British investigators in science as a mark of appreciation of distinguished work, particularly in such fields as fuel economy, chemical engineering, and metallurgy, in which Sir George Beilby's special interests lay. In general, the awards are not applicable to the more senior investigators but are granted as an encouragement to relatively young men who have done independent work of exceptional merit over a period of years.

Foundry Prize of Sheffield University

A reorganization of the courses in the Department of Metallurgy has meant that no student will, in future, take a degree in Founding Metallurgy, although he would have some experience in foundry work. In the past the Council of The Iron and Steel Institute has awarded an annual prize of £10 10*s*. 0*d*. on the results of the final examination for the degree of B.Met. (Founding). In view of the changed circumstances, the Council has agreed to amend the conditions governing the award so that the prize should go to the student producing the best papers on "Iron and Steel" and "Melting and Casting."

Institution of Mining and Metallurgy

The Gold Medal of the Institution of Mining and Metallurgy has been awarded to Dr. George Kenneth Williams, B.M.E., D.Eng., M.I.M.M., in recognition of the importance of his work in connection with research into the metallurgy of lead and zinc and the development of metallurgical processes.

Massachusetts Institute of Technology

The new Metals Processing Laboratory of the Massachusetts Institute of Technology was dedicated on Tuesday, 3rd June. The ceremony was followed by a two-day technical conference on metal cutting.

The George Fischer Iron Library

On 3rd May, 1952, the Iron Library, a foundation of George Fischer Ltd., Schaffhausen, Switzerland, was formally dedicated. The Library, inaugurated in December 1948, has been set up in the ancient 'Paradies' Convent, which was taken over by the Company in 1918.

As well as accommodating the archives of the firm the Library contains about 8000 books, some of an early date, and manuscripts of the 13th–18th centuries. It is hoped that the Library will become a centre for the custody of historical and contemporary literature on the

production and working of iron and relevant subjects and for the promotion of research into the history of iron.

The convent buildings provide accommodation for board meetings of the Company, and visitors may be accommodated in the old guest house in the precincts of the Convent.

American Society for Testing Materials

Mr. C. L. WARWICK, Executive Secretary of the American Society for Testing Materials, and its administrative head since 1919, died suddenly on 23rd April, 1952, after presiding at a dinner held in honour of the retiring Treasurer.

Protection and Electrodeposition of Metals

The third volume of Selected Government Research Reports has been published for the Department of Scientific and Industrial Research by H.M.S.O. The first 20 reports deal with the protection of magnesium alloys, the protection of steel, the polishing of aluminium alloys, the study of intercrystalline attack, and the operation of corrosion tests. Research into electroplating problems is dealt with in thirteen reports, which form the second part of the book. Methods of determining unwanted constituents of plating solutions are included. Chemical and magnetic methods of measuring the thickness of deposited coats, and adhesion tests for use during the inspection of plating, are described.

The report is available from H.M.S.O., price £1 10*s*. 0*d*.

Harwell—The First Five Years

"Harwell," published by H.M.S.O. (price 6*s*.), is the first official account of the work and problems of the Atomic Energy Research Establishment, Harwell, from its inception in 1946 up to the end of 1951. The main research programmes and the progress achieved are listed under four heads: the production programme, isotopes, nuclear reactors, and particle accelerators. Some of the fundamental research in the fields of physics, chemistry, and metallurgy, is also described.

Many of the researches in metallurgy are of fundamental interest in metal physics—such as the study of the unusual crystal structure of uranium, which at room temperature is orthorhombic in form. Other metallurgical subjects reviewed in the book are uranium alloy systems, powder metallurgy, the examination of metals under polarized light, the effects of irradiation on the mechanical properties of metals, and fabrication of high-temperature materials such as alumina and zirconia.

D.S.I.R. Technical Information Service

The D.S.I.R. Headquarters Technical Information Service has been merged with the Technical Information and Documents Unit. The new unit retains the name TIDU. Its address is Cunard Building, 15, Regent Street, S.W.1. (Telephone : Whitehall 9788).

The unit holds the German industrial documents which were brought back to this country after the war. It is receiving unpublished reports from British and American sources and it issues summaries of them. Many of these reports contain information which is not published in the normal way.

The New Cold-Reduction Mill at Trostre Works

The new 5-stand cold-reduction mill at the Trostre works of the Steel Company of Wales, which started operation seven months ago, has now proved its productive capacity. On Monday, 5th May, during an 8-hr. shift, the mill rolled 452½ tons of steel strip into thin tinplate gauges—twice as much as has ever been rolled before in this country in the same period.

The mill, which is capable of rolling at a speed of 4500 ft./min., normally operates at 3000 ft./min., and during this record shift it rolled at a rate of 9000 tons per week, which represents 180,000 boxes of tinplate. The operators have all been drawn from old-type tinplate works in South Wales, and have been trained at the Trostre works on the mill itself.

A New Development in Core-Binding Technique

Aero Research, Ltd., have recently introduced a new form of synthetic resin core-binder, 'Resolite' 400, which is said to have overcome the difficulty of stickiness commonly associated with resin-bonded mixes, and to facilitate core-making on the bench and in core-blowing machines.

American Iron and Steel Institute

It was announced at the Annual Meeting of the American Iron and Steel Institute, held in New York on 21st and 22nd May, 1952, that Mr. Walter S. Tower would retire from the Presidency of the Institute. Mr. Tower has been President since 1940; he had previously held the appointment of Executive Secretary for 18 years.

Mr. Max. D. Howell succeeded to the new office of Executive Director to the Institute on 23rd May, 1952.

Company Appointment

Sir WILFRED EADY, whose retirement from the Treasury was recently announced, has been appointed a Director of Richard Thomas and Baldwins, Ltd., and Director of the Steel Company of Wales, Ltd.

DIARY

30th June–4th July—2ND INTERNATIONAL CONFERENCE ON HOT-DIP GALVANIZING—Düsseldorf.

TRANSLATION SERVICE

(The previous announcement was made in the June, 1952, issue of the *Journal*, p. 184.)

TRANSLATIONS AVAILABLE

No. 446 (German). E. WITTEN: "Metallurgy of Iron, Manganese, and Phosphorus Reactions in Basic Steelmaking." (*Archiv für das Eisenhüttenwesen*, 1952, vol. 23, Mar./Apr., pp. 83–93).

No. 447 (German). K. HEINRICH: "The Use of Oxygen in Basic Open-Hearth Furnace Operation." (*Stahl und Eisen*, 1951, vol. 71, Nov. 8, pp. 1199–1204).

No. 448 (French). P. ROCQUET and C. G. THIBAUT: "Statistical Study of Some Factors in Relation to the Composition of the Iron from the Blast-Furnace." (*Revue de Métallurgie, Mémoires*, 1951, vol. 48, Apr., pp. 303–313).

TRANSLATION IN COURSE OF PREPARATION

(French). J. COURTHEOUX: "The Rolling of Angles." (*Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques*, 1952, vol. 9, No. 4, pp. 534–542).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

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MINERAL RESOURCES

The Plant in Action—Cornelly Quarry: Location and Geology. D. J. Isaac. (*Iron Coal Trades Rev., Special Issue*, 1951, 112–116). After a brief outline of the location and geology of the Cornelly Quarry of the Steel Company of Wales, Ltd., which supplies limestone to the Company's blast-furnaces and melting shops, details are given of the quarry practice and of the modernization scheme completed in 1947.—G. F.

Iron Ore Supply for the Australian Steel Industry. (*Engineer*, 1952, **193,** Jan. 25, 155–156). A brief description is given of the new iron ore supplies for Australian Iron and Steel Ltd. —now merged with the Broken Hill Proprietary Co., Ltd. The ore is to come from Cockatoo Island, some 3000 miles away, in four vessels of 12,500 tons. A description of the ore deposit is given with details of mining, crushing, and conveyor equipment.—M. D. J. B.

Evolution of Technical Methods in the Lorraine Iron Mines. (*Rev. Ind. Min.*, 1952, **33,** Jan., 39–66). The general characteristics of the Lorraine ore deposit and the evolution of mining technique since before the war are reviewed; output figures are given. Heavy capital investment is needed to enable new equipment and techniques to be adopted.—A. G.

Mining and Metallurgical Industry in Finland. E. Mäkinen. (*Z. Erz. u. Met.*, 1951, **4,** Dec., 445–446). Many areas of Finland are still geologically incompletely surveyed. Copper, nickel, zinc, lead, iron, cobalt, tungsten, gold, silver, arsenical, and sulphurous ores are mined. Some are refined in the country, some exported as such. The iron ores contain TiO_2, and concentrates containing 66% Fe and 5% TiO_2, as well as titanium concentrates containing 45% TiO_2 are exported. Iron ores for home iron production are imported. Steel is made mainly from imported pig iron and scrap. A blast-furnace, a Tysland-Hole electric furnace, an electric steel furnace, and a rolling mill are in operation.—P. F.

The Minerals of Bicsad, Rumania. J. Erdélyi. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1,** 2, 1–46). [In German]. A mineralogical analysis of ores and stones in quarries in western Rumania is presented. Pseudobrookite, apatite, magnetite, hematite, titanite, and other minerals found are described.—P. F.

ORES—MINING AND TREATMENT

A Development in Opencast Ironstone Mining. (*Engineer*, 1952, **193,** Feb. 29, 302–304). A description is given of a new method of overburden blasting, developed for the fragmentation of a seam of limestone in the ironstone mines at Corby, Northamptonshire, of Stewarts and Lloyds Minerals, Ltd., to make possible the safe and economic operation of a 1650-ton walking dragline in close proximity to the highwall edge.—M. D. J. B.

The Preparation of Kahlenberg Fine Iron Ores. G. Sengfelder. (*Z. Erz. u. Met.*, 1951, **4,** Oct., 374–377). The fine fraction of Kahlenberg iron ores (particle size $< 0{\cdot}3$ in.), is highly acid owing to a considerable amount of silica contamination. Mechanical and electromagnetic means of separating this fine fraction into a calcium-rich part having a suitable CaO/SiO_2 ratio, and an iron-rich fraction are described. Details of the principles involved, and the equipment employed, including that for making pellets are given.—P. F.

Concerning the Theory of Magnetic Separation of Weakly Magnetic Ores. V. P. Derkach. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, No. 6, 852–862). [In Russian]. Magnetic separators for weakly magnetic ores are discussed, and an analysis of magnetic and mechanical forces acting on pieces of ore is made.—V. G.

Fundamental Studies on Interfacial Tensions in Flotation. I—Determination of Surface Tension with Data on Aqueous Solutions of Frothers. M. Wada. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Aug., 121–131). Surface tension measurements are described, full particulars of the technique, based on the ring method, being given.—J. G. W.

FUEL—PREPARATION, PROPERTIES, AND USES

Fuel, Heat and Power Auditing. L. Clegg and J. Price Walters. (*Inst. Fuel Preprint*, Mar. 18, 1952). This paper describes the work of the mobile testing units of the Fuel Efficiency Branch of the Ministry of Fuel and Power. An account is given of experience gained in practice and an example is put forward to illustrate what a fuel, heat, and power audit involves. Its value is stressed.—J. P. S.

Flame Radiation Research Joint Committee: Reports of 1949 Trials at Ijmuiden. Purposes and Plan of the Experiments. J. E. de Graaf and M. W. Thring. (*J. Inst. Fuel*, 1951, **24,** Nov., s2–s3). An increase in existing knowledge on heat transfer by luminous radiation is necessary before an improvement in the thermal efficiency and output of boilers can be made. Laboratory measurements of luminous emissivity can only be applied to industrial problems if taken under conditions where burning, mixing, and heat exchange occur at the same relative rates as in a full-scale furnace. The experimental flame must not be scaled down by more than 2 or 3 to 1 and the furnace walls must be at the appropriate distance from the flame. A series of performance trials carried out in such a furnace was planned so as to include the following five independent variables: (1) Oil and creosote

pitch as fuels; (2) high and low fuel input rate; (3) air and steam as atomizing agent; (4) high and low quantity of atomizing fluid; and (5) high and low quantity of excess air. The trials were designed to give information on the development of instruments for use in furnaces, the accuracy of their readings, and furnace control.—J. P. S.

Flame Radiation Research Joint Committee. Reports of 1949 Trials at Ijmuiden. Review of Previous Work on Luminous Radiation. F. M. Comerford. (*J. Inst. Fuel*, 1951, **24**, Nov., s4–s7). Chemical, physical, and engineering methods have been employed in the previous study of luminous radiation. The chemical mechanism whereby soot particles can be built up from gaseous molecules is not yet fully understood, but preferential combustion, cracking, and polymerization all seem to play a part. The physical approach shows that the fine soot particles which are the source of the luminous radiation may be treated as being in thermal equilibrium with the surrounding gases, but are so small as to be partially transparent so that the emissivity of the flame varies with the wavelength of the radiant energy.—J. P. S.

Flame Radiation Research Joint Committee. Reports of 1949 Trials at Ijmuiden—Heat-Flow Meters. R. T. Fowler. D. A. Richardson, and M. Rivière. (*J. Inst. Fuel*, 1951, **24**, Nov., s8–s9). The heat-flow meters used on the experimental furnace to measure the radiant heat energy received by a cold body at different points along the furnace are described and the calibration results obtained before and after the trials are presented. The meters were found to have a mean error of 10%, the scatter for any one calibration being of the order of 20%. Variations in the value of the true absorption factor suggest that this error is mainly due to inaccuracies of calibration and that the instruments are probably more accurate than the calibration figures suggest.—J. P. S.

Gas Burners and Combustion Systems. H. F. Rehfeldt. (*Indust. Heating*, 1951, **18**, Nov., 1976–1984, 2132; Dec., 2164–2176). Equipment commonly employed with gas-fired furnaces is fully described. The widely used atmospheric burner system and the two-pipe system using gas and air at various pressures are considered. Various mixing devices for the latter are described. Atmospheric burners are discussed in connection with their combustion systems. Diagrams of various systems are reproduced.—B. G. B.

Progress Review No. 18: Oil-Burning Equipment. G. J. Gollin. (*J. Inst. Fuel*, 1951, **24**, Nov., 265–267, 276). Recent progress in America and Europe on domestic burners, and industrial burners for steam raising and industrial furnaces is reviewed.—J. P. S.

Use of High-Pressure Gas in the Open-Hearth. M. P. Burns. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 311–316). Steam, compressed air, and high-pressure coke-oven gas and natural gas as atomizing agents for liquid fuel firing of open-hearth furnaces are considered. The use of natural gas in this respect during trials at the Fairfield works of the Tennessee Coal, Iron and Railroad Co. is described, the results showing that steam and natural gas are equally efficient as atomizers.—G. F.

Measurement and Control of Steel Works Power Plants. W. L. Besselman. (*Amer. Soc. Met.: Blast Furn. Steel Plant*, 1951, **39**, Dec., 1506–1508, 1536). The Metermax combustion control system is described. The system is electro-pneumatic and measures the flow of fuel, primary and secondary air (forced and induced draught), balances these against the steam header pressure, and automatically adjusts the various control devices to maintain the desired combustion conditions. Power measurement and load-frequency control are discussed.—J. P. S.

The Influence of Molecular Mass of Solid Surfaces on the Heat Exchange with Gases. E. Sänger. (*Métaux-Corrosion-Indust.*, 1952, **27**, Jan., 44–45). A mathematical expression is derived for the rate of heat exchange; it is shown how the molecular masses of the solid and gas are connected with the efficiency of heat exchange.—B. G. B.

The Best Arrangement of Tubes in Heat Exchangers. E. Eckert. (*Forsch. Ingenieurwesens*, 1949–50, **16**, 5, 133–140). For a given heat transfer through a specified heating surface, close spacing of the tubes gives the least pressure drop and smallest overall size; the spacing should therefore be as close as production technique and considerations of fouling permit. Cross flow is better than parallel flow, particularly at low Reynolds numbers, and under those conditions the rows should preferably be staggered.—H. R. M.

Uniform Method of Calculation for Heat Exchangers. F. Bošnjaković, M. Viličić and B. Slipčević. (*Forsch. Ingenieurwesens*, 1951, **17**, *VDI-Forschungsheft* 432, 5–26). Recuperative heat exchangers can be characterized by the ratio of the heat transmitted to the difference between the inlet temperatures of the two fluids. Families of curves showing the relation between this characteristic, the rates of flow of the two fluids, and the area of the heating surface, are given for a number of different types of heat exchanger (parallel flow, counter flow, cross flow). The characteristic of a combination of heat exchangers can be calculated from a knowledge of their individual characteristics.—H. R. M.

Approximate Solution of a Transient Heat Flow Problem. J. H. Blackwell and A. D. Misener. (*Proc. Phys. Soc.*, 1951, **64A**, Dec. 1, 1132–1133). Approximate solutions are obtained to the problem of measuring the thermal constants of an infinite medium of low conductivity. A thermal probe, containing a source of heat and some form of thermometer, is inserted into the medium, and a record obtained of temperature within the probe *versus* time elapsed. From this record the thermal constants can be evaluated approximately by solving the appropriate heat equations.—C. J. B. F.

Heat Transfer in Laminar Flow along a Flat Plate with Non-uniform Surface Temperature. H. Schlichting. (*Forsch. Ingenieurwesens*, 1951, **17**, 1, 1–8). A method of analysis is developed for calculating the heat transfer, velocity, and temperature distribution for the case of laminar flow along a flat plate having an arbitrary distribution of surface temperature.—H. R. M.

Nomenclature, Classification, and Examination of Mineral Coals. W. Radmacher. (*Glückauf*, 1951, **87**, Nov., 1093–1105). Methods used for classifying mineral coals, and the classification by rank adopted in several coal-producing countries are tabulated, and the standards used for the determination of volatile components and of ash content are described. A detailed discussion of methods for the complete analysis of coal is given, including determination of the swelling, and coking properties. A proposal is made for an international standard classification for coals, and reference is made to international bodies now considering this question. (46 references).—P. F.

The Plant in Action—Coal Handling and Preparation, Coke Ovens and By-Products. B. E. Blackledge and H. J. Victory. (*Iron Coal Trades Rev., Special Issue*, 1951, 117–120). The authors describe the design and operation of the new additional coke ovens installed during the reconstruction of the Margam works of the Steel Company of Wales, Ltd. They also deal with the new washery, the coal-preparation plant, and the new coke-screening and by-product plant.—G. F.

Coal Utilization in Modern Steelworks Practice. J. D. Norgard and W. H. Brook. (*Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 255–278). The author discusses: Fuel consumption in smelting; gas firing; characteristics of New South Wales coals; coal for coking; coal cleaning; composition of ash; coal for gas producers; and coal for steam raising and by-product fuels. He advocates greater use of oxygen-enriched air and better refractories.—J. P. S.

Froth-Flotation of Coal. E. Hindmarch and P. L. Waters. (*Trans. Inst. Min. Eng.*, 1952, **111**, Feb., 221–235). A short historical survey and an account of the scientific principles are followed by descriptions of laboratory investigations. It is shown that low-rank coals can be economically upgraded. The preparation of superclean coal is described, and the flow sheet of a proposed modern plant is given.—T. E. D.

Choice of a Single Coefficient to Represent the Accuracy of Separation—A Proposal for International Standardization. T. Eder. (*Rev. Ind. Min.*, 1951, **32**, Dec., 479–482). At the International Conference on Coal Preparation in Paris, June, 1950, the term 'imperfect' was used to represent the results of separation by specific gravity (as in dense media and jig washers). A more general standard is put forward applicable to sieving, decantation of slurries, pneumatic dust removal, and centrifuging.—A. G.

Experiments on Preparing Komló Coal for Coking by the Wet Method. G. Tarján. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1**, 2, 133–163). [In German]. Results of experiments carried out by the author on preparing Komló lias coal for coking by the wet method are given in numerous tables and diagrams. The 'heavy-media' method and flotation are recommended.—P. F.

Scientific Utilization of Coal for Coking. A. Lahari. (*Journal of Scientific and Industrial Research*, 1951, **10A**, Dec., 475–481). The author shows that the resources of good quality coking coal in India are not unlimited. The best chance of a permanent solution to the problem lies in the adoption of modified carbonization and blast-furnace techniques by which the iron and steel industry can dispense with superior grades of coking coals. This has been successfully achieved in the U.S.A.—J. P. S.

Coke Oven Cost Analysis. W. B. Knuff. (Eastern States Blast Furnace and Coke Oven Assoc.: *Blast Furn. Steel Plant*, 1951, **39**, Dec., 1477–1480, 1491). The importance of control of expenditure is stressed as a minor increase in the coke cost can become a major cost increase in the end product. Senior officials are therefore quickly acquainted with coke, pig iron, and ingot costs so that prompt action can be taken for the correcting of possible operating mistakes. A cost system designed to give maximum control is outlined.—J. P. S.

Initial Firing and Putting into Operation of Silica-Brick Coke Ovens. W. Schulte-Mattler. (*Glückauf*, 1952, **88**, Jan., 13–21). The correct method of initially firing silica brick coke ovens, by gas or coal is described. The shrinkage of silica bricks due to the transformation of quartz into crystobalite and tridymite is explained, and a heating-up schedule for the temperature control is put forward. The construction of the framework for modern coke ovens is discussed, and the heat consumption of a battery is considered.—P. F.

Concerning Sulphur in Coal and Coke. H. Mainz. (*Glückauf*, 1951, **87**, Nov., 1045–1053). The degree of sulphur removal in high-temperature coking is variable within comparatively wide limits. The effects of the initial free and combined sulphur contents and of the coking temperatures on the amount removed during coking were investigated using several coals. Most of the pyritic sulphur is removed at about 545° C., but the loss of the organic sulphur, which takes place only at about 675° C., is much less complete. About 30–40% of the total sulphur is removed in coking.—P. F.

A New Contribution to the Theory of Coking. E. S. Kardos. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1**, 2, 125–132). [In Russian]. The hydrogen, oxygen, and carbon contents of carbonaceous materials and the coking properties of Hungarian coals are given, and the data are used in a critical examination of the recent theories developed independently by Szádeczky (1947–49) and Berkowitz (1949), which assume, contrary to previous concepts, that coking is not materially affected by the bituminous materials, which only help to inflate the coke by the liberation of combustible gases in coking. All theories assume a closed structure of coal which prevents the escape of these gases and facilitates the swelling of the coke. Szádeczky has demonstrated this structure microscopically. Coking capacity is not determined exclusively by the chemical composition of the coal but also by the nature of its closed-cell structure.—P. F.

Gasification by the Moving Burden Technique. J. W. R. Rayner. (*Inst. Fuel Advance Copy*, Dec. 18, 1951). The disadvantages are considered of the conventional method of making water gas by carbonization of coal to coke and subsequent gasification of the coke to steam. German processes for the production of water gas from low-rank coals such as lignites are reviewed. The introduction of the fluidized-solids process for catalytically cracking petroleum suggested a new technique possibly applicable to gasification methods. The three processes involved—carbonization, reaction between steam and coke, and combustion of part of the gas or coke to provide heat for the reactions—were at first carried out in three interconnected vessels. A description is given of the semi-technical-scale plant of this type installed at Billingham for the gasification of coke dust.—J. P. S.

Mechanical Engineering Aspects of Coke Works Practice. L. S. Freebury. (*Gas World*, 1952, **135**, Mar. 1, 210–223). The items covered include coal handling, with special reference to belt conveyors. Coal crushing and oven-charging plant design are discussed. Details of coal leveller, door extractor, and pusher mechanisms are given, and a measure of standardization is suggested. Coke quenching plant, handling equipment, screens, by-product plant, and maintenance are considered.—T. E. D.

The Quality of Blast-Furnace Coke. F. J. Hewitt, H. L. Riley, and P. Savage. (*Iron Steel*, 1952, **25**, Feb., 63–64; *Gas World*, 1952, **135**, Mar. 1, Coking Section 7–15). Coke quality is judged by a 'micro-strength' test and a 'wet-oxidation' test is discussed. The study of half-oven widths is described and the data obtained are correlated to carbonization time. Many results from United Steels and National Coal Board coke ovens are quoted.—T. E. D.

The Strength of Coke. A. Romwalter. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1**, 2, 75–82). [In German]. The strength of coke and the coking properties of coals are studied on the basis of the strength of crystals. It is shown that reactivity and strength are mutually opposing properties. Iron in the coke increases its strength. Ash content is an unsuitable indicator of strength or reactivity.

Foundry Coke. H. A. Stephens. (*J. Inst. Australian Foundrymen*, 1950, **2**, 139–159). The author first reviews types of coal and their suitability for the production of metallurgical coke. The types of oven used, and the mechanism of coke formation are described. The properties of cokes and the special requirements of foundry cokes are tabulated, and the properties of Australian cokes are considered in relation to foundry requirements.—P. M. C.

Gasification Diagrams. F. Bošnjaković. (*Forsch. Ingenieurwesens*, 1951, **17**, VDI-Forschungsheft 432, 27–40). New diagrams are given for the determination of enthalpy, temperature, and composition of producer gas produced under different working conditions. Particular consideration is given to the gasification of coke, but the influence of fuel composition is also examined.—H. R. M.

Corrosive Constituents in Producer Gas. M. L. Khanna. (Indian Science Congress: *Journal of Scientific and Industrial Research*, 1952, **11**, Jan., 23–24). Producer gas samples from 32 gas producers all using charcoal from different sources as fuel, were analysed. The range of variation in the constituents (percentage volume) was found to be: CO, 15·0–27·3; CH_4, 0–2·5; H_2, 0–5·3; CO_2, 1·0–7·6; O_2, 0·7–5·3; SO_2, 0–0·1; NH_3, 0–0·024; N_2, 65·8–77·8. Methods of diminishing the amount of impurities are outlined.—J. P. S.

Industrial Applications of Sonic Energy. C. R. Soderberg. (*Iron Steel Eng.*, 1952, **29**, Feb., 87–94). The author discusses problems inherent in the collection of mists and fumes by sonic means and describes the industrial applications of sonic equipment and the development required before it can be used on an industrial scale. He suggests applying it to collect carbon black, sulphuric acid, and open-hearth fume. Fundamental principles and operating data are given with graphs showing the results of pilot-plant tests.—M. D. J. B.

Calculation of Dust Removal from Smokes by Means of Nomograms. J. Breuil. (*Chim. et Ind.*, 1952, **67**, Feb., 235–241). Methods of calculation, by means of nomograms, of the size of settling chambers and the dimensions of centrifugal dust catchers are explained.—T. E. D.

Contribution to the Kinematics of the Cyclon and Cyclon Scrubbers. G. Tarján. (*Acta Technica Academiae Scientiarum Hungaricae*. [In German]. An analysis of the design and performance of cyclon separators used for solids suspended in liquid or gaseous media is given, and the results are illustrated by means of practical examples relating to the separation of magnetite, quartz grains, and coal dust in aqueous suspension, as well as for dust particles in a gas.—P. F.

Automatic Control Systems for the Coal Feed of Gas Producers. S. A. Burke, and G. A. Sparham. (*J. Inst. Fuel*, 1951, **24**, Nov., 257–264). A series of tests was made on a Morgan Producer at the steelworks of John Baker and Bessemer, Ltd., at Kilnhurst, Yorkshire, to develop and compare new methods for the automatic regulation of the coal-feed rate. The systems tested were: (*a*) Use of gas off-take temperature alone as the controlling variable; and (*b*) direct proportioning of coal feed to air flow, using gas off-take temperature merely as a slow resetting integral action.—J. P. S.

TEMPERATURE MEASUREMENT AND CONTROL

Bath Pyrometry. W. T. Sergy. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 185–195). A comparison of the immersion thermocouple with the blowing-tube radiation pyrometer at the Pittsburgh plant of the Jones and Laughlin Steel Corp. indicates that the former is of greater reliability and more desirable for production use. The author discusses the benefit ascribed to the use of bath pyrometers, and from data relating bath temperature with ladle skull and defectives, concludes that the optimum tapping temperatures for rimming steel and low-carbon aluminium-killed deep-drawing steel are respectively 1580–1600° C. and 1560–1580° C.

An example of proper temperature control during a heat is presented.—G. F.

Recent Development in Open-Hearth Bath-Temperature Control. T. J. Hoby and R. J. McCurdy. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34,** 196–202). The author describes the construction and use of the immersion thermocouple at the South Chicago plant of the Republic Steel Corp. The benefits ascribed to its use include savings in fuel and refractories, improved ladle life, and more consistent quality.—G. F.

Open-Hearth Bath Pyrometry, K. J. Vogel. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34,** 202–205). The author describes the use of the Leeds and Northrup immersion pyrometer at the Edgar Thomson works of the United States Steel Co. and discusses the benefits obtained. The specific temperature ranges established for various grades of steel, the frequency of unreliable readings, and the nature of the adjustments performed when readings are outside the desired range, are also considered.—G. F.

Some Measurements of the Total Emissivity of Metals and Pure Refractory Oxides and the Variation of Emissivity with Temperature. A. H. Sully, E. A. Brandes, and R. B. Waterhouse. (*Brit. J. Appl. Phys.*, 1952, **33,** Mar., 97–101). A method is described for the rapid determination of the total emissivity of metals and oxides in the 300–800° C. range. Values have been obtained for stainless steel and other materials. The total emissivities of the pure oxides ceria, zirconia, thoria, magnesia, alumina, and fused silica have also been determined.—J. P. S.

Temperature Control Equipment. (*Metal Ind.*, 1952, **80,** Jan. 25, 73). Two newly developed Sunvic temperature controllers are described. The type R.T.2 is an electronic proportional resistance thermometer controller, covering the range 30–1140° C. in six steps. The instrument is unaffected by changes in supply voltage. A new thermostatic relay, type E.D.2, which operates without snap action is also described. This is recommended for extremely close temperature control at low temperatures. A water bath of simple design can be controlled within $\pm$ 0·02° C.—P. M. C.

Immersion Pyrometry in the Steel Industry. F. Mortimer. (*Metallurgia*, 1952, **45,** Feb., 88–90). A brief general account mentions present practice and future trends in view of increasing open-hearth bath temperatures.—T. E. D.

Proportional Temperature Control. R. Scott. (*Electronic Eng.*, 1952, **24,** Mar. 117). As an alternative to the use of saturatable inductors for the proportional control of heating, a means of controlling power dissipation by an electronic circuit is described, embodying a system for switching the heater for various fractions of a continuously repeated timing interval.—H. D. W.

Notes on Pyrometry. G. M. Wolten. (*Metal Progress*, 1951, **60,** Nov., 91–92). Precautionary notes are given on the temperature measurement of the furnace, furnace charge, and furnace gas. Surface-temperature measurement outside the furnace is also considered.—J. P. S.

Flame Radiation Research Joint Committee. Reports of 1949 Trials at Ijmuiden. Total Radiation Pyrometers. E. J. Burton, R. Mayorcas, M. Michaud, W. H. Pritchard, and M. Rivière. (*J. Inst. Fuel*, 1951, **34,** Nov., s10–s11). Two types of radiation pyrometer were used during the engineering trials: The mirror pyrometer developed to measure the total radiation from the flame backed by a water-cooled slot, and the diaphragm pyrometer which measured the radiation from the refractory surfaces either directly or through the flame. In both types Moll thermopiles gave good reproducibility.

Flame Radiation Research Joint Committee. Reports of 1949 Trials at Ijmuiden. Suction Pyrometry. I. M. D. Halliday. (*J. Inst. Fuel*, 1951, **24,** Nov. s12–s14). The development of an improved suction pyrometer is outlined. The author describes comparative tests made between a standard single tubular-hood type of pyrometer and two experimental designs incorporating improved shielding of the thermocouple to increase accuracy (*a*) by an outer tubular hood and (*b*) by a bundle of small-bore tubes round the thermocouple. The design adopted for use in an experimental furnace is described in detail.—J. P. S.

Flame Radiation Research Joint Committee. Reports of 1949 Trials at Ijmuiden. The Main Experiments. R. Mayorcas. (*J. Inst. Fuel*, 1951, **24,** Nov., s15–s26). The absolute accuracy of the results and the causes of variations between trials are assessed. The accuracy of the radiation measurements is concluded to be of the order of 5%. An appendix by G. W. Stein Callenfels describes the furnace, and its control and instrumentation.—J. P. S.

REFRACTORY MATERIALS

The Composition of Refractory Mixes. F. Savioli. (Assoc. Ital. Met.: *Met. Ital.*, 1952, **44,** Jan., 14–16). The problem of determining the proportion of binding material in mixes for making refractory bricks is examined. There must be sufficient binder present to fill the space between the grains of lean material and cement them together. Volumetric changes during firing are studied and examples of calculations of the proportions to be mixed are presented.—M. D. J. B.

Studies on Ceramic Raw Materials. Part II. Reduction of Ferric Iron by Feldspars. H. N. Das Gupta and S. K. Chatterjee. (*J. Indian Chem. Soc.*, 1951, **28,** Oct., 569–584). Ferric compounds suffer reduction in feldspar melts. The mechanism of this reduction is explained and is supported by experimental evidence.—T. E. D.

The Calcination of Dolomite. Part I—The Kinetics of the Thermal Decomposition of Calcite and of Magnesite. Part II—The Thermal Decomposition of Dolomite. H. T. S. Britton, S. J. Gregg, and G. W. Winsor. (*Trans. Farad. Soc.*, 1952, **48,** Jan., 63–69; 70–75). The kinetics of the isothermal decomposition *in vacuo* of calcite (720–780° C.) magnesite (540–600° C.) and dolomite (640–720° C.) were studied. Values obtained for the energy of activation E, of the decomposition are (cal. mole^{-1}), for calcite, 35,000 $\pm$ 4800 and 41,600 $\pm$ 2900; for magnesite 35,600 $\pm$ 3300; for dolomite 55,600, 53,800, 49,400, and 52,300. The mechanism of the decomposition of dolomite is discussed.—T. E. D.

Reaction Temperatures between Refractories. L. A. McGill and J. S. McDowell. (*Bull. Amer. Ceram. Soc.*, 1951, **30,** Dec., 425–431). The nature of the chemical reactions between bricks of different types in contact at high temperatures is discussed. The test procedure is explained. Reactions with fired chrome, chemically bonded chrome–magnesite, fired chrome–magnesite, high-duty fireclay, forsterite, 70% Al_2O_3 (diaspore base), 90% Al_2O_3 (corundum base), fired magnesite, chemically bonded magnesite–chrome, and conventional silica are examined. The reaction of silicon carbide with burned chrome brick is also discussed. Tables of the results and photographs showing the effects of the reactions between various types of brick are included.—E. C. S.

Simplified Method of Determining the Resistance of Refractory Materials to Slag Attack. V. M. Strelets and V. V. Radin. (*Zavodskaya Laboratoriya*, 1950, No. 1, 108–109). [In Russian]. A method is described for determining the resistance to slag attack of various refractory materials. No special apparatus is required. The basis of the method is the measurement of the decrease in volume of the specimen of standard dimensions after immersion in slag. The specimen is 62 mm. in dia. The temperature is raised to 1450° C. at an average rate of 11° C./min. in a Kryptol furnace.—S. K.

Wetting of Solid Phases with Molten Silicates. K. P. Azarov. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **82,** 1, 79–82). [In Russian]. Among other solid materials the wettability of the various oxides of the group VIII metals by molten silicate glass was investigated.—V. G.

Crystallographic Data of Silicon Carbide VIII. E. B. Gasilova and M. I. Sokhor. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **82,** 2, 249–251). [In Russian]. Crystallographic data of a new type of silicon carbide called by the authors SiC VIII are given.—V. G.

The Electrical Properties of Oxide Mixtures as an Index of Structural and Phase Changes at High Temperatures. W. F. Ford and J. White. (*Trans. Brit. Cer. Soc.*, 1952, **51,** Jan., 1–79). Refractory oxide mixtures at high temperatures exhibit an electrical conductivity which is complex in nature; it is attributable partly to ionic conductance and partly to absorption conductance arising from the presence of relaxing units. A summary of the fundamental knowledge relating to ionic conductors and dielectrics is followed by a review of previous practical work and a description of the apparatus developed to measure at audio-frequencies and, under equilibrium conditions, the resistance, capacity, and loss angles of CaO–Al_2O_3–SiO_2 mixtures freezing at 1266° C.—E. J. D. S.

Low-Alumina Silica Bricks. 3—Raw Materials. W. Davis. (*Trans. Brit. Cer. Soc.*, 1952, **51,** Feb., 95–112). The paper describes the search for low-alumina quartzites by the Oughtibridge Silica Firebrick Co., Ltd., the materials selected,

and their properties. Three types of quartzite were studied: (1) Coarse-grained, low in titania, (approximately 0·1%); (2) chalcedonic quartzite with similar titania content; and (3) chalcedonic quartzite high in titania (1·5% or more), including Findlings quartzites and South African silcretes. These materials contained less than 0·5% alumina.—E. J. D. S.

Low-Alumina Silica Bricks. 4—Manufacture. T. R. Lynam, A. Nicholson, and P. F. Young. (*Trans. Brit. Cer. Soc.*, 1952, **51,** Feb., 113–135). By investigation it was found that the presence of alumina in contact with quartzite helps to give a slow inversion, leading to trouble-free firing. Unfortunately, a high alumina content promotes the formation of miscible melts which result in short service life. A coarse-grained pebble and a chalcedony with the lowest alumina contents had no melt in contact with the quartz and resulted in delayed but rapid kiln inversion. However, a low-alumina quartzite consisting of small strained grains presented no particular manufacturing difficulties. The presence of titanium in silcrete was found to facilitate inversion at low temperatures and to produce a brick free from kiln-firing faults. Silcrete in silica bricks is an advantage because porosity values as low as 16% can be obtained.—E. J. D. S.

Low-Alumina Silica Bricks. 5—Properties and Performance. J. Mackenzie. (*Trans. Brit. Cer. Soc.*, 1952, **51,** Feb., 136–157). A theoretical approach to the study of silica raw materials and their utilization is discussed. From a study of thermal equilibrium diagrams the effects of impurities on the melting point of silica may be assessed. These effects enable the impurities to be divided into two groups. One, which includes CaO, MgO, FeO, and MnO, contains oxides which form two immiscible liquids over a wide range of composition with melting points only a little below that of pure silica. The second contains impurities which cause a rapid decrease in melting point as a eutectic composition is approached. This group includes Al_2O_3, TiO_2, and the alkalis. Some open-hearth furnace roof trials using silcrete bricks are described.—E. J. D. S.

Recent Technical Progress in Basic Steel Furnace Refractories. Part III. J. I. Cordwell. (*Refract. J.*, 1951, **27,** Nov., 467–475). The term 'dolomite' is defined and the three main classes of natural rocks containing the carbonates of calcium and magnesium are described, *e.g.*, calcariferritic, calcareous dolomites, and magnesian calcites. Several investigations leading to the effective stabilization of dolomite, and the application of this material to steelmaking furnaces, are briefly described.—E. J. D. S.

Silica *versus* Basic. R. T. Lynam. (*Refract. J.*, 1952, **28,** Jan., 19, 22). The value of silcrete bricks for open-hearth furnace roofs is discussed, and it is suggested that these bricks will compete with basic bricks for this application because of the metallurgical and economical factors influencing the choice of the all-basic furnace for steelmaking.—E. J. D. S.

Observations on the Behaviour of Firebricks on Reheating. A. H. B. Cross and P. F. Young. (*Trans. Brit. Cer. Soc.*, 1952, **51,** Jan., 80–94). Although the dimensional changes of a firebrick on being reheated may vary from one part of the brick to another, there is, in general, a systematic trend. The degree of variability may be related to previous thermal and physical history of the brick as much as to inherent characteristics of the clays employed. Volume measurements are a more reliable indication of the behaviour during reheating than linear measurements. The reheat test for firebricks, in its present form, is unsuitable for inclusion in specifications.

Quality of Silica Brick. W. S. Debenham and G. R. Eusner. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 129–138). The authors describe a reheat test which provides a suitable means of determining the relative refractoriness of silica bricks and evaluating the quality of the available brands. Typical test results obtained are given.

Combination Basic and Silica Brick in Open-Hearth Roof Construction. C. G. Poth. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 142–156). The author describes the trials of alternate courses of basic and silica brick (the 'zebra' construction) in open-hearth furnace roofs at the Massillon plant of the Republic Steel Corp. The advantages of this type of construction include an increase in roof life of 45% and in campaign life of 60%, a 75% decrease in the amount of roof patching necessary, and an increase in furnace availability time. The longer roof life has also enabled 15-in. roofs to be replaced by 12-in. roofs. The experiences of other firms with similar constructions are described in the discussion.—G. F.

Open-Hearth Bottoms. H. M. Kraner and G. H. Anthony. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 157–161). The authors briefly discuss the advantages and disadvantages of the various types of open-hearth furnace bottoms, and emphasize the importance of correct building and maintenance to obtain the best production rate.

Open-Hearth Furnace Bottoms, Fairfield Steel Works. C. C. Benton. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 162–172). The author describes the construction and maintenance of open-hearth furnace bottoms at the Fairfield works of the Tennessee Coal, Iron and Railroad Co. Methods in use at the Lukens Steel Co. and the proposed use of a carbon block sub-hearth at the Buffalo plant of the Republic Steel Corporation are also described in the discussion.—G. F.

Importance of Ladle Lining. C. E. Sumpter. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 172–178). The author describes the ladle-lining practice at the Chicago works of the United States Steel Co., and emphasizes the necessity for high-quality brick, good workmanship, and balanced lining wear. Lining methods in use at other works are also described in the discussion.—G. F.

Linings for Hot-Metal Mixers. K. D. Bartels. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 178–183). A description is given of trials of various types of hot-metal mixer linings at the Homestead plant of the United States Steel Co. The various bricks used included blast-furnace quality fireclay, high-fired superduty fireclay, burned and unburned chrome–magnesite, sillimanite, and 70% alumina. The best results obtained to date are with sillimanite in the areas of severe erosion and blast-furnace quality fireclay in the remaining parts, all laid with sillimanite or other high-grade mortar.—G. F.

A Monolithic Lining for Cupolas. J. L. Willis. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 257–258). A monolithic lining for the cupolas used to supply molten iron for the open-hearth furnaces at the Central Iron and Steel Co., Pennsylvania, is described, and the advantages and disadvantages of the practice are enumerated.—G. F.

Refractories and Their Performance in Cold-Metal Shops. P. B. Akin. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 261–262). The author discusses the refractories' performance in the Laclede Steel Company's cold-metal open-hearth shop at Alton, Illinois. Furnace life is increased by the use of basic brick for end-seals, front walls, and for all-basic ends. Roof life is increased by the use of 'superduty' silica brick and by the 'zebra' construction.

Refractory Dollars Show a Profit. H. C. Paxson. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 263–265). The author briefly outlines how basic bricks in the ends and front walls and the use of 'superduty' silica bricks has helped to avoid production losses in the cold-metal open-hearth shop of the Lukens Steel Company, Coatesville, Pennsylvania.—G. F.

Use of Superduty Silica Brick in Open-Hearth Roofs. C. M. Kay. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34,** 266–267). The author briefly describes the use of 'superduty' silica brick in the critical areas of the cold-metal open-hearth furnace roofs at the American Steel and Wire Co., Worcester, Massachussetts. The practice has resulted in increased roof life.—G. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Blast Furnace Installation. (*Elect. Rev.*, 1951, **149,** Dec. 21, 1245–1255). The electrical installations from quayside to pig casting and slag tip at the blast-furnace plant at the Margam section of the Steel Company of Wales are described. The 3·3-kV. supply is fed through bare steel conductors to a transformer on the main trolley on the ore bridge. Transfer cars of 100 tons and 50 tons are used and are fed by a third rail conductor. The equipment for crushing, elevating, and conveying ore by belt is included. Details are also given of the blowers, stove blowers, clay gun, ladle tilters, casting strands, and electrostatic gas cleaners.—H. D. W.

Recent Developments in Blast Furnace Practice. J. K. Branchwood. (*Proc. Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 151–172). A very brief outline

is given of some of the new developments in blast-furnace design and practice.—J. P. S.

Margam Reconstruction. L. Griffiths. (*Iron Coal Trades Rev., Special Issue*, 1951, 12–22, 34). The author describes in some detail the extensive reconstruction of the Margam works of the Steel Company of Wales, Ltd., dealing mainly with the blast-furnace plant, its ore wharf, and the adjacent coke ovens.—G. F.

Construction: Blast-Furnace Skip Pits and Foundations. Andrew Scott (Civil Engineers) Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 94–95, 157). This article describes the construction of the blast-furnace skip pits and blast-furnace foundations at the Margam works, and the open-hearth furnace foundations at Margam and Port Talbot works, of the Steel Company of Wales, Ltd.—G. F.

The Plant in Action—Margam Blast Furnaces. R. Frost. (*Iron Coal Trades Rev., Special Issue*, 1951, 121–129). The author describes the layout and operation of the new blast-furnace plant at the Margam works of the Steel Company of Wales, Ltd., dealing mainly with ore handling and preparation, the furnaces and stoves, casting machines, and gas-cleaning plant.—G. F.

High Top Pressure Operation or Burden Preparation—A Survey of Differences in Blast Furnace Practice in the United States and Great Britain. D. D. Howat. (*Blast Furn. Steel Plant*, 1952, **40**, Jan., 71–76). As a result of preparatory treatment the burden charged to the blast-furnaces in Britain is much more open and permeable than in United States practice. In Britain, dust production is low but the output of iron and the coke burned per unit area of the 6-ft. annulus are comparable with United States figures. The author discusses the importance and calculation of the speed of the gases through the furnace. An outline is given of the advantages and disadvantages of high top pressure operation. High top pressure for smelting magnetite ore is discussed.—J. P. S.

Blast Furnace Built in Less than a Year. (*Blast Furn. Steel Plant*, 1951, **39**, Dec., 1496–1499). The history of a blast-furnace built by John Mohr and Sons, Chicago, for Dominion Foundries and Steel, Ltd., Hamilton, Ontario, in less than a year is outlined. Details of the furnace (capacity: 850 short tons/day) are given.—J. P. S.

A New 1000-Ton Blast Furnace. C. H. L. Schneider. (*Demag News*, 1951, No. 126, 13–17). An illustrated description is given of a new blast-furnace at the Hüttenwerk Hoerde designed for a coke consumption of 1000 tons/24 hr. The hearth is 22 ft. 10 in. in dia., and this, together with the bosh, is lined with carbon ramming material. The Demag bucket-charging system with buckets of 410 cu. ft. capacity carrying 18 tons of ore is employed.—R. A. R.

Removal and Replacement of Blast Furnaces at Pueblo Expedited by Blasting. (*Indust. Heating*, 1951, **18**, Dec., 2216–2218). Details of the controlled demolition of a blast-furnace are given. The new shell, already erected 100 ft. away, was moved on skids to the old foundations.—B. G. B.

Reduction Equilibria of Iron Oxides. I—Measurement of the Equilibrium of Reaction Fe_3O_4 (in Wüstite) + CO = 3FeO (in Wüstite) + CO_2. K. Sanbongi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A., 1949, **1**, Oct. 213–222). This reaction was studied in the range 700–1200° C., whence the equilibrium constant was calculated. From this and the dissociation constant of CO_2 the author calculated the equilibrium between wüstite and H_2O–H_2 gas, and the dissociation pressure of wüstite, and also the activities a_{FeO} and $a_{Fe_3O_4}$ in wüstite at several oxygen concentrations.—J. G. W.

Reduction Equilibria of Iron Oxides. II—Measurement of the Equilibrium of the Reaction FeO(l) + CO = Fe(s) + CO_2. K. Sanbongi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Apr., 296–304). The author measured the equilibrium of the above reaction in the temperature range 1360–1490° C. and found that $\log K_{CO-CO_2} = (7680/T) - 5{\cdot}37$. Secondly, he calculated the equilibrium constant of the reaction FeO(l) + H_2 = Fe(s) + H_2O and obtained the function $\log K_{H_2-H_2O} = (6390/T) - 4{\cdot}07$. Finally he calculated the dissociation pressure of the reaction FeO(l) = Fe(s) + $\frac{1}{2}O_2$, and obtained the function $\log P_{O_2^{\frac{1}{2}}} = -(23{,}000/T) + 10{\cdot}39$.—J. G. W.

About the Nature of Molten Ferrous Silicates and the Solution of Ferrous Sulphide in Them. Ya. I. Ol'shanskii. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **81**, 1, 67–70). [In Russian]. It is suggested that in the series Fe, FeS, FeO, FeO + SiO_2 in the liquid state there is a continuous gradation from metallic to ionic bonds. It is deduced that molten FeO + SiO_2 solutions possess not only ionic but also electron conductivity. These considerations form the basis of the explanation of the effect of various additions to molten ferrous silicates on the solubility of ferrous sulphide.—V. G.

The Influence of Carbon on the Activity of Sulphur Dissolved in Liquid Iron. A. M. Samarin and L. A. Shvartsman. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, No. 3, 407–410). [In Russian]. It is suggested that the influence of carbon on the activity of sulphur in liquid iron can be explained by the assumption that the number of available places for carbon and sulphur in the solution is approximately equal to one quarter of the number of iron atoms, and that atoms of sulphur and carbon cannot be present simultaneously in the same unit cell of a melt.—V. G.

The Influence of the Concentration of Carbon Monoxide in Gases on the Reduction of Iron Ores and Agglomerates. L. M. Tsylev. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, No. 1, 74–79). [In Russian]. The influence of the concentration of carbon monoxide in gases on the velocity of reduction of iron ores at between 600° and 1000° C. was investigated.—V. G.

PRODUCTION OF WROUGHT IRON

Some Notes on Wrought Iron. L. Sanderson. (*Eng. Boiler House Rev.*, 1951, **66**, Nov., 335–340). After dealing briefly with the composition, properties, and structure of wrought iron, its treatment and uses, particularly in the production of pipes, are described.—E. C. S.

PRODUCTION OF STEEL

Developments in the Iron and Steel Industry During 1951. I. E. Madsen. (*Iron Steel Eng.*, 1952, **29**, Jan., 103–141). After giving total production figures and referring to the economic position of the steel industry in the U.S.A. the author describes the expansion programme in the industry. Reference is also made to Canadian, Mexican, Brazilian, British, German, French, Russian and Russian-controlled, Austrian, and Indian plants. The position of raw materials, particularly ore, is considered. All the stages in the production of steel are reviewed.—M. D. J. B.

Some Recent Developments in the Iron and Steel Industry of North America. R. H. Parker. (*Swansea Met. Soc.*, 1952, Mar. 15, 1–20). A general review covers iron ore supplies, ore beneficiation, and coke and furnace practice. In connection with blast-furnace operation, high top pressure and modulated blowing are discussed. In basic open-hearth steelmaking, the use of 550-ton furnaces, works layout, the use of oxygen, and coke-oven-gas firing are described.—T. E. D.

A Review of the War-Time Activities of the Newcastle Steel Plant of the Broken Hill Pty. Co. Ltd., and Its Associated and Subsidiary Industries. D. O. Morris. (*Proc. Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 69–139). The special war-time problems of the various departments of the above works are discussed. Details are given of the armament production carried out by the company during the war years.—J. P. S.

Plans for Steel Mill in Peru. (*Times Review of Industry*, 1952, **6**, Mar., 85). The site for the steel mill at Chimbote possesses reasonably adjacent supplies of ore, coal, and electric power. There are 60 million tons of hematite ore available near the surface at Marcona. An initial target of 60,000 tons/annum of steel is planned.—T. E. D.

The Elimination of Defects in Metallurgical Plant. J. S. Caswell. (*Swansea Met. Soc.*, 1951–52, 1–32). The basic requirements for the attempted elimination of defects causing plant breakdown are summarized. These include good design, planning and materials in plant manufacture and erection, correct loading and maintenance in plant operation, and periodic routine search for signs of incipient failure. Good design and type of loading are examined in detail, and three methods of stress analysis are described.—T. E. D.

Oxygen As a Means of Increasing Bessemer Production. W. G. McDonough. (*Yearbook Amer. Iron Steel Inst.*, 1951, 164–184; *Indust. Heating*, 1951, **18**, Sept., 1595–1602, 1680; Dec., 2211–2214, 2218; 1952, **19**, Jan., 71–80). Experiments with oxygenated blast on a 28-ton acid-Bessemer converter are described. A description of the Bessemer plant layout and operation as well as the oxygen plant and piping system is given. Experimental oxygen blows, varying oxygen volume, rate of flow, and time of input are discussed.—J. A. L.

Preliminary Planning of Margam and Abbey Works. W. F. Cartwright. (*Iron Coal Trades Rev., Special Issue*, 1951, 9–12). This article briefly outlines the preliminary planning of the Margam and Abbey works of the Steel Company of Wales, Ltd., and discusses some of the decisions which had to be taken in designing the new plant.—G. F.

The Work of the Consulting Engineers : Layout and Planning of the Abbey Works. International Construction Co., Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 23–34). This article describes the work of the overall consulting engineers in the layout and planning of the Abbey works of the Steel Company of Wales, Ltd. This includes the supervizing of the site organization, the co-ordination of the work at site, and the detailing of numerous items of plant and equipment.—G. F.

The Work of the Consulting Engineers : Civil Engineering and Buildings. W. S. Atkins and Partners. (*Iron Coal Trades Rev., Special Issue*, 1951, 35–56). This article describes the civil engineering work in the construction of the Abbey works of the Steel Company of Wales, Ltd., and in particular the layout and design of the buildings. Maximum use has been made of continuity, both transversely and longitudinally, in all the structures.—G. F.

The Work of the Consulting Engineers : The Electrical and Steam Systems for Port Talbot, Margam, and Abbey Works. McLellan and Partners. (*Iron Coal Trades Rev., Special Issue*, 1951, 57–75). The electrical power supply and distribution systems of the new Abbey works and the reconstructed Port Talbot and Margam works of the Steel Company of Wales, Ltd., are described in some detail. The design and control of the electrical machinery are discussed, and the steam services are also briefly considered.—G. F.

The Work of the Consulting Engineers : Central Engineering Shop—Production of Parts and Maintenance. H. Orensten. (*Iron Coal Trades Rev., Special Issue*, 1951, 76–79, 93). The layout and operation of the new central engineering shop of the Margam and Abbey works of the Steel Company of Wales, Ltd., are briefly described. The shop is organized to manufacture spare parts and to carry out repair work.—G. F.

The Work of the Consulting Engineers: Architectural Design. Sir Percy Thomas and Son. (*Iron Coal Trades Rev., Special Issue*, 1951, 80–81). This article briefly describes architectural design at the Abbey and Margam works and the new Trostre cold strip mill of the Steel Company of Wales, Ltd. The firm acted as consulting architects for the general design of the whole buildings, and as architects for all ancillary buildings.—G. F.

Construction : Civil Engineering for Margam Works Reconstruction. Sir Robert McAlpine and Sons (South Wales) Ltd. (*Iron Coal Trades Rev., Special Issue*. 1951, 82–93). The civil engineering and building work, particularly in connection with the foundations at the Margam plant of the Steel Company of Wales, Ltd., is described in detail, and the problems encountered and factors affecting design are dealt with.—G. F.

Construction : Civil Engineering for Melting Shop and Hot Mill—Abbey Works. George Wimpey and Co., Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 96–106, 111). Civil engineering for the melting shop and hot mill of the new Abbey works of the Steel Company of Wales, Ltd., is considered and the preparation of the site, piling, and construction of the foundations are described by the firm in some detail.—G. F.

Construction : Raising the Abbey Site Level. Mears Brothers (Contractors), Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 110–111). The raising of the level of the low-lying site for the new Abbey works of the Steel Company of Wales, Ltd., was undertaken by Mears Brothers (Contractors), Ltd. The normal dry-filling and hydraulic pumping methods and the dredging equipment employed are briefly described.

The Plant in Action—Steel Plant Operations. R. W. Evans. (*Iron Coal Trades Rev., Special Issue*, 1951, 130–145). The author gives details of the layout and operation of the Port Talbot, Margam, and Abbey melting shops of the Steel Company of Wales, Ltd. The three plants satisfy the requirements of the new Abbey slabbing mill and of the Port Talbot heavy bar mill.—G. F.

Trostre Works—Engineering Background : Civil Engineering and Superstructures. A. J. Williams. (*Iron Coal Trades Rev., Special Issue.*, 1951, 172–176, 211) After briefly describing the selection of the site for the new Trostre works of the Steel Company of Wales, Ltd., the author discusses the project with particular reference to civil engineering and the erection of superstructures.—G. F.

Work of the Consulting Engineers—Civil Engineering Design for Construction of Main Foundations. L. G. Mouchel and Partners Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 177–183).

Construction : Civil Engineering for Trostre Works. R. M. Douglas (Contractors) Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 184–189).

Effects of Low-Manganese Pig Iron on Open-Hearth Operations. J. A. Hornak. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 27–42). The author describes a statistical study of the effects of variation in pig-iron manganese content on open-hearth furnace operations. It is shown that an increase in the pig-iron manganese content results in slightly increased manganese when tapping, decreased bath and ladle manganese recoveries, decreased lime and dolomite consumption, and slightly increased desulphurization. Ladle manganese additions are at a minimum with 1·35% Mn in the pig iron. The effect on final manganese, output rate, and final quality is insignificant.—G. F.

Methods of Increasing Inland Steel's Open-Hearth Production. G. C. Lawton. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 43–50). The author describes methods in use at the East Chicago plant of Inland Steel Co., for increasing production. He discusses scrap preparation and methods of decreasing charging time and other delays, and then considers the furnace operation, including flush-off practice, oxygen injection, and sizing of limestone.—G. F.

Increase in Ingot Production by the Use of Oxygen. E. H. Leathers and C. W. Drabers. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 53–56). The authors describe how the ingot production at the Wheeling Steel Corp., Steubenville, Ohio, has been increased by about 36%, largely through the use of oxygen in the open-hearth furnaces. The oxygen consumption per ton of steel is about 520 cu. ft. for combustion and 80 cu. ft. for decarbonization.—G. F.

Increasing Armco Steel Corporation's Open-Hearth Production. W. W. Bergmann. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 58–59). The author briefly describes the improvements in charging technique at the No. 1 open-hearth shop of the Armco Steel Corp., Middletown, Ohio. An increase in production of over 5% during 1950 is largely attributed to these improvements.—G. F.

Increasing Production at the Kaiser Open-Hearth Plant. W. F. Bowers. (*Amer. Inst. Min. Met., Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 61–63). Methods used at the Kaiser Steel Corp. to increase open-hearth production are briefly described. The factors discussed include scrap preparation, decreasing charging time and other delays, furnace operation, and finishing practice.—G. F.

Methods of Increasing Open-Hearth Production. E. J. Dattisman. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 64–65). Methods of increasing open-hearth production at the Homestead works of the United States Steel Co. are briefly outlined. The methods include reduction of tap-to-charge time, scrap preparation and selection of charge ores, firing at maximum fuel rates, and improving finishing practice. The importance of maintaining the morale of the workers is also emphasized.—G. F.

Availability of Open-Hearth Furnaces, Sparrows Point Plant. R. M. Baker. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 70–76). Methods in use at the Sparrows Point plant of Bethlehem Steel Co. for reducing furnace repair time to a minimum and increasing furnace availability are outlined. Special attention is given to cleaning the slag pockets, and the importance of furnace control is also mentioned.—G. F.

Furnace Availability at Ford Motor Company. M. J. Smith. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 78–79). Methods used at the Ford Motor Co. to increase furnace availability, including the introduction of an incentive pay system in an effort to decrease furnace rebuild time, are briefly described.—G. F.

Use of Basic Brick to Increase Availability at Weirton Steel Company. S. J. Dougherty. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.*, 1951, **34**, 80–81). This paper summarizes the experience of the Weirton Steel Co. in the use of basic furnace ends and ' zebra ' roofs, and shows the resulting increase in furnace availability.—G. F.

Furnace Design for Increased Production. D. R. Loughrey. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 93–98). The author discusses the design of open-hearth furnaces from the viewpoint of increasing production rates. He deals with the construction of the roof, front and back walls, and furnace bottom, and the design of the uptake, checkers, and flues. In general the observations apply to a 250–300-ton furnace, with a firing rate of 600–750 U.S. gal./hr. of tar or fuel oil.—G. F.

Furnace Design for Increased Production. J. M. Brashear. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 98–101). This paper describes the design of the open-hearth furnaces at the East Chicago plant of the Inland Steel Co. and gives details of the effect of changes in design on the production rate.—G. F.

Furnace Design and Shop Arrangement for Increased Production. J. L. Hyland. (*Amer. Inst. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 102–107). As a means of increasing production rates, the Republic Steel Corp. is building and operating larger open-hearth furnaces at its Buffalo, Cleveland, Chicago, and Gadsden plants. The author briefly describes the layout of the Cleveland melting shop and the changes in furnace design, and indicates the resulting increase in production rate.—G. F.

Some Metallurgical Advantages of the Acid Open-Hearth Process. H. P. Rassbach. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 109–115). The author compares the acid open-hearth process with other steelmaking processes and discusses some of the metallurgical advantages of the acid process. He deals mainly with the closer control of oxygen content and rate of carbon removal in the acid process, and the lower susceptibility of acid steel to hair-line cracking.

Types of Charges and Their Effects on Production Rates. A. R. Altman and E. Walkowski. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 120–125). The authors describe an investigation carried out at the Heppenstall Company, Pittsburgh, to determine the effect of the type of charge on the production rate of acid open-hearth steel. Data are presented which show that production rate is decreased by the introduction of carbon substitutes for some of the pig iron, and by the replacement of clean heavy scrap by rusty light scrap.—G. F.

Factors Affecting Spread in Manganese between First and Last Ingots of Rimming-Steel Heats. M. Tenenbaum and C. C. Brown. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 208–213). The authors indicate the general conditions existing in a ladle of rimming steel which can be conducive to a drop in manganese content between first and last ingots. Such conditions are a high state of oxidation, low temperature, low residual manganese, and extensive ladle-brick erosion.—G. F.

Factors Affecting Spread in Manganese between First and Last Ingots. R. D. Hindson. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 214–219). The author presents data obtained from several hundred heats at the Hamilton works of the Steel Company of Canada, Ltd., which indicate that the variation in manganese between first and last ingots of a heat depends upon the type of steel, its manganese and silicon contents, the time held in the ladle, the basicity of the tapping slag, and the type of ladle lining. Methods of controlling this variation are suggested, and it is emphasized that such control would enable heats to be tapped in the lower part of the manganese specification range, thus effecting considerable savings in manganese.—G. F.

Factors Affecting the Surface Quality of Killed Steel Containing 0·15 to 0·20 and 0·40 to 0·55 Per Cent Carbon. L. W. Fleming. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 222–225). The author discusses the effects of furnace and deoxidation practice, sulphur and manganese contents, teeming practice, and transit time on the surface quality of 0·15–0·20% C and 0·40–0·55% C steels. Methods of improving the product at the Gary works of the United States Steel Co. are also considered.—G. F.

Factors Affecting Surface Quality of 0·40 to 0·55 Per Cent Carbon Killed Steel. A. E. Reinhard. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 225–226). The surface quality of 0·40–0·55% C killed steel is discussed, and the precautions which must be taken in tapping and teeming this class of steel, and in soaking the ingots, are outlined.—G. F.

Factors Affecting Surface Quality of 0·40 to 0·55 Per Cent Carbon Killed Steel. D. J. Taylor. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 227–230). The author discusses factors affecting the surface quality of 0·40–0·55% C killed steel, made by the duplex process at the Aliquippa works of the Jones and Laughlin Steel Corp. The steelmaking practice and casting-pit and soaking-pit conditions are considered.—G. F.

Factors Affecting Surface Quality of 0·40 to 0·55 Per Cent Carbon Killed Steel. A. K. Moore. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 230–234). Data from the Hamilton works of the Steel Company of Canada, Ltd., are presented, relating quality of 0·40–0·55% C killed steel to mould conditions, sulphur content of the steel, teeming rate, track time, soaking time, and rate of carbon drop.

Production of Mechanically Capped Steel over 0·15 Per Cent Carbon. E. N. Hibbert. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 234–237). The author gives brief details of the method of producing mechanically capped steel, with over 0·15% C, at the Ohio works of the United States Steel Co. The major features of the practice are the low melt sulphur; furnace practice leading to a well-oxidized bath tapping at 0·10% C, recarburizing in the ladle; and the use of sodium fluoride in the moulds to aid the rimming action.—G. F.

Steel-Plant Process Control. J. L. Scarry and D. A. Hayes. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 238–247). The authors describe the work of the process-control personnel at the Homestead works of the United States Steel Co. Some of the particular problems encountered at the plant are discussed.—G. F.

Control of Low-Carbon and Killed Steel for Deep-Drawing Quality. A. E. Reinhard. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 247–249). The production of deep-drawing rimming and low-carbon aluminium-killed steels at the Great Lakes Steel Corp. is briefly described. The precautions taken in the furnace practice and teeming conditions are discussed.—G. F.

Manufacture of Low-Carbon Rimmed and Killed Steels for Deep Drawing. K. L. Fetters. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 250–252). The author discusses the production of low-carbon deep-drawing grades of rimming and aluminium-killed steels at the Youngstown Sheet and Tube Co., and describes briefly the process control and precautions taken.—G. F.

Linings for Cupolas in Open-Hearth Shops. P. R. Sultzbach. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.* 1951, **34**, 254–256). The author briefly describes the use of cupolas, melting 35% cast iron and 65% steel scrap, in conjunction with the open-hearth furnaces at Stanley works, Bridgeport, Connecticut, Particular attention is given to factors affecting the life of the cupola lining.—G. F.

High-Iron Ore Charges for Cold-Metal Heats. H. M. Parker. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 259–260). A description is given of the practice at the Butler plant of the Armco Steel Corp. of charging iron ore in heats melting a high proportion of cold metal. The practice has the purpose of reducing tramp element content and charging time.—G. F.

Preparation of Scrap. W. H. Steinheider. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 273–275). The author presents data showing the effect of charging rate on open-hearth heat times, and describes the method of scrap preparation at the Sheffield Steel Corporation, Kansas City, which has been developed with the object of increasing the charging rate.—G. F.

Flow Patterns in Open-Hearth Furnaces. J. H. Chesters. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 282–306). The author summarizes the principal deductions from the flow-pattern work on water models of open-hearth furnaces at the laboratories of the United Steel Companies Ltd. (*see J. Iron Steel Inst.*, 1952, **171**, June, 199).

Use of Treated Water for Cooling Open-Hearth Equipment. B. Dagan. (*Amer. Inst. Min. Met. Eng.*: *Proc. Nat. O.H. Comm.*, 1951, **34**, 325–328). The treatment and recirculation of open-hearth furnace cooling water at the Fontana plant of the Kaiser Steel Corp. is briefly discussed, and the beneficial effect of the removal of solid matter on the life of the cooling equipment is described.—G. F.

Automatic Control of Open-Hearth Furnaces. A. Benda. (*Hutník*, (Prague,) 1952, **2**, 1, 8–9). [In Czech]. Methods of automatically controlling fuel input, fuel/air ratio, pressure at hearth level, and reversal of the air flow through the checkers are discussed.—P. F.

The Application of Quality Control in Steel Operations, Ford Motor Company. H. W. Clark. (Michigan Society for Quality Control: *Blast Furn. Steel Plant*, 1952, **40**, Jan., 64–70; Feb., 201–207). All raw materials are screened before unloading and steel scrap is examined for contamination or foreign elements while it is being unloaded. Scrap is allocated to the furnaces in such a manner as to prevent excessive charging time. The chemical composition of the molten iron to be charged into the open-hearth furnaces is known before charging. Close control is maintained when tapping the furnace and in the subsequent treatment of the ingots. Statistical quality control has been applied to the rolling mills since 1949. Weekly quality-control charts for the cold-rolling mill are described and explained.—J. P. S.

Operation and Control of an All-Basic Open Hearth Furnace. J. Mitton. (*Refract. J.*, 1951, **27**, Oct., 410–420). This paper was presented to the Junior Steelmaking Conference, organized by B.I.S.R.A., at Ashorne Hill in June, 1951. An outline is given of the operating conditions studied, performance, and port and roof construction of a 56-ton tilting open-hearth furnace at Stewarts and Lloyds, Ltd., Bilston, after its final conversion from acid to all-basic construction.

Vanadium in the Acid Steelmaking Process and Its Reducing Power. I. A. Popov and V. B. Stark. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Teckhnicheskikh Nauk*, 1951, No. 2, 261–266). [In Russian]. The behaviour of vanadium in the acid steelmaking process was investigated. From the experimental data the following equilibrium-constant/temperature relationships were obtained:

$$\log\ Kv = \log\,[V]\,(FeO)^2 = -\frac{10{,}900}{T} + 7{\cdot}28$$

$$\log\ K'v = \log\,[V]\,[FeO]^2 = -\frac{23{,}700}{T} + 10{\cdot}10$$

Statistical Thermodynamical Studies on the Fundamental Reactions Concerning Steelmaking. I. (S. Takeuchi and S. Kachi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Oct., 691–718). [In English]. The authors examine the equilibria between γ-iron and CO–CO_2 gas mixtures and between molten iron and H_2–H_2O or CO–CO_2 gas mixtures by statistical thermodynamics. The second equilibrium is discussed.—J. G. W.

On the Equilibrium between Iron, Sulphur and Hydrogen at High Temperatures. S. Matoba and T. Unotoro. (*Technology Reports, Tôhoku University*, 1949, **14**, 1, 60–76). [In English]. The first part is concerned with the reduction equilibrium of ferrous sulphide by hydrogen, and the second part with the reduction equilibrium of ferrous sulphide in molten iron. Equations expressing the results are presented.

The Surface Tension and Structure of Silicate Slags. T. B. King. (*J. Soc. Glass Techn.*, 1951, **35**, Oct., 241–259). A dipping-cylinder method was used to measure the surface tension of simple silicate slags at high temperature. The relationship between surface tension and composition was found to be approximately linear in the binary systems CaO–SiO_2, MnO–SiO_2, FeO–SiO_2, and MgO–SiO_2. Silica lowered the surface tension of the basic oxides, but was not particularly surface active. Dietzel's use of the cation–oxygen field strength as a measure of the variation in surface tension between one silicate and another was applied to several metasilicates, and high field strengths were associated with positive coefficients of surface tension. An attempt is made to explain this behaviour in terms of the ionic view of liquid slags and, by analogy, with glasses.—E. J. D. S.

The Effect of Stirring on the Rate of Desulphurizing Carbon-Saturated Molten Iron with CaO–SiO_2–Al_2O_3 Slags. C. E. A. Shanahan. (*Metallurgia*, 1951, **45**, Feb., 59–61). Evidence from laboratory experiments is presented to show the beneficial effect of stirring on desulphurization of carbon-saturated Armco iron at 1430° C. by CaO–SiO_2–Al_2O_3 slags.—T. E. D.

Some Recent Advances in Metallurgy. G. P. Contractor and B. S. Sreekantiah. (*Journal of Scientific and Industrial Research*, 1952, **11**, Jan., 20–22). Oxygen-enriched blast in iron and steel furnaces increases thermal efficiency, gives higher temperatures, increases calorific value of blast gases and speeds up the processes. Continuous steel casting allows faster cooling of the charge and results in a uniform crystalline structure with very little segregation. The new radioactive tracer technique is being increasingly employed for process control in metallurgy, *e.g.*, in continuously checking the phosphorus in an open-hearth heat.—J. P. S.

Should the Steel Industry Move Closer to Liquid Charging? J. O. Griggs. (*Blast Furn. Steel Plant*, 1952, **40**, Jan., 41–57). The author proposes top charging of open-hearth furnaces. Its advantages would include a great saving in scrap-yard area and a reduction of 75 cents per short ton in cost of preparing scrap. Most of the doors could be reduced in size by two-thirds. Uniform charging would result in increased production and better control of steel quality. One charging machine would serve 12 furnaces.—J. P. S.

Multiple Burners in Open Hearth Furnaces. H. T. Watts. (*Amer. Iron Steel Inst.*: *Blast Furn. Steel Plant*, 195, **39**, Dec., 1484–1491; *Iron Steel Eng.*, 1951, **28**, Dec., 102–107). The principal variables affecting the operation of open-hearth burners are given and the history and design of multiple burners and the improvement in efficiency obtained are discussed.—J. P.

Steel Flows from Jones & Laughlin's $70,000,000 Open-Hearth Furnace Addition. (*Blast Furn. Steel Plant*, 1951, **39**, Dec., 1492–1495). The expansion project includes construction of 11 new open-hearth furnaces to be completed by March, 1953. Details of the design of the furnaces are given and new auxiliary equipment and its layout are described.

Comparative Economics of the Electric Furnace and Open Hearth. H. W. McQuaid. (*Iron Steel Eng.*, 1952, **29**, Jan., 85–92). The author suggests that the modern are furnace can, under most conditions, compete economically with the modern open-hearth furnace. The technical and economic reasons for this are discussed in detail. Electric furnaces are particularly useful where production requirements are small and where the alternative would be a cold-charge open-hearth plant. Increase in electric furnace steelmaking is prevented by the present scrap scarcity.—M. D. J. B.

Jet Tapper Practice at the Open Hearth. H. Walker and A. R. Almeida. (National Safety Council: *Iron Steel Eng.*, 1951, **28**, Dec., 108–109). The advantages of 'jet tapping' with a small explosive charge (*see J. Iron Steel Inst.*, 1952, **170**, Jan., 67) are discussed.—R. A. R.

The Prospects of the Electric Furnace in Ferrous Metallurgy. (*J. Four Elect.*, 1951, **60**, Nov.–Dec. 152–153). The advantages of the electric furnace for the production or treatment of special alloy steels are stressed. The construction and use of large electrodes has now been perfected. The possible development of the reduction of iron ores in the electric furnace is reviewed. The cost of electricity should be reduced by the construction and operation of new hydro-electric schemes. The advantages and disadvantages of the electric furnace compared with the open-hearth are reviewed.—B. G. B.

What Are Present Limits to Electric Furnace Size. J. L. Bray. (*Iron Age*, 1951, **168**, Dec. 13, 127–130). The factors which may be expected to limit the size of electric arc furnaces are considered, and it is suggested that the limit for a three-electrode arc furnace is probably 150 tons, if there are no new major electrical developments. At high currents the losses become disproportionately great and beyond a certain limit heat may be generated faster than it can be disseminated through the bath, in addition the demand for electric furnace steels is usually limited to small orders.—A. M. F.

We Learn from Melter Žuravlev's Experience. V. Keclik. (*Hutník*, (Prague), 1952, **2**, 1, 5–7). [In Czech]. The design of the electric furnaces at the Moscow Elektrostal plant and in the Poldi steelworks is discussed. In the former considerable experience has been gained with chrome–magnesite roofs. Alloy steel production with acid, basic, and with calcium carbide slags is discussed, and the recovery of chromium, vanadium, manganese, and other elements from the slag after the boil and their return to the melt are described. The advantages of bottom-pouring are enumerated; organization and planning of work of the furnace team are described.—P. F.

Metal Alloying: Continental High-Vacuum Furnace. (*Elect. Rev.*, 1952, **150**, Feb. 15, 355–356). **Vacuum Melting.** (*Metal Ind.*, 1952, **80**, Feb. 22, 145–146). A detailed description is given of a furnace operated by Gerätebau-Anstalt

Balzers, Lichtenstein, for the melting of metals for special alloys. The contamination of the melt by oxidization is avoided by enclosing the furnace and mould with a hopper charging device in a large vacuum chamber.—H. D. W.

Rugged Vacuum Furnace Built for Semi-Production Use. J. M. Taub and D. T. Doll. (*Iron Age*, 1951, **168**, Nov. 15, 125–128). A practical all-metal vacuum furnace which will melt from 5 to 50 lb. of metal is described. A minimum of quartz compounds or glass is applied and the chief metal used is stainless steel. The furnace is divided into the two main parts of an upper heating and melting tank and a lower mould-containing tank. Heating can be by either a resistance or an induction coil and the existing pumping equipment easily maintains pressures of 5 microns or less.—A. M. F.

Three Laboratory Furnaces for High Temperatures. R. L. Bickerdike. (*Métaux-Corrosion-Indust.*, 1951, **26**, Oct., 415–421). An arc furnace, operating under vacuum or argon atmosphere, is first described. This has a water-cooled electrode with a tungsten tip. The maximum current used is 400 amp. at 40 V. A tungsten resistance furnace is next considered, and, finally, a high-frequency furnace capable of heating samples up to 2000° C.—B. G. B.

Bottom Casting of Ingots for the Manufacture of Plates. T. T. Watson. (Amer. Iron Steel Inst.: *Blast Furn. Steel Plant*, 1951, **39**, Dec., 1471–1475, 1491; *Indust. Heating*, 1952, **19**, Feb., 265–280). Bottom-pouring practice is the best for making good-quality small ingots for the manufacture of steel plates. The quality of the steel produced is equal to that obtained in top-pouring practice and a higher plate yield is obtained. Details are given for the design of bottom plates, centre runner, and bottom runner brick. The assembling of the bottom plate, the design of the moulds, the scheduling of ingot groups, ingot yield, metallurgical practice, and pouring practice are discussed. The methods for producing rimming steel and silicon-killed steel are outlined. The average increase in plate yield obtained with bottom-poured ingots is approximately 5%.—J. P. S.

The Possibilities of the Continuous Casting Steel. M. Schneider and E. Zalsinski. (*Hutník* (Katowice), 1952, **19**, 1, 1–6). [In Polish]. A survey of literature concerning the continuous casting of steel is given, and various aspects of this process are discussed.—V. G.

Hot Topping Practice. W. T. Sergy. (*Amer. Inst. Min. Met. Eng.*: *Blast Furn. Steel Plant*, 1952, **40**, Jan., 89–90). The Pittsburgh works of the Jones and Laughlin Steel Corp. employ a permanent-type hot top for ingot moulds. It has been possible to reduce the volume of the sink head by approximately 3% on slab ingots. The advantages of the re-usable type of hot top outweigh the merits of the non-re-usable type. Hot-top insulating materials have a limited use in present plant practice.—J. P. S.

Improved Feeder-Head Tile for Ingot Hot Tops. H. O. Howson. (*Metal Progress*, 1951, **60**, Nov., 88–90). Refractory tiles, recessed at the back leaving a working thickness of ¾ in., for ingot mould hot tops are described. Extensive trials have shown a complete absence of spalling and lives as long as three times those of conventional tiles have been obtained.—J. P. S.

Cooling of Rimming Steel Ingots in a Casting Pit. R. T. Fowler and L. H. W. Savage. (*J. Iron Steel Inst.*, 1952, **171**, July, 277–288). [This issue].

Inclusions in Steel. L. A. S. Perrett. (*Swansea Met. Soc.*, Presidential Address, 1951, Oct. 13, 1–16). The nature and origins of inclusions in steel are reviewed.—T. E. D.

FOUNDRY PRACTICE

Supervision of Foundry Raw Materials. F. Roll. (*Giesserei*, 1952, **39**, Feb. 7, 49–54). The author urges closer control of the quality of raw materials purchased by the foundry and illustrates his argument by showing the effects of variations in the various materials used.—J. G. W.

Design of Iron Castings. K. H. Collinson. (*Found. Trade J.*, 1952, **92**, Feb. 28, 217–221). The author considers the needs of the foundryman, and the even more important technical and aesthetic requirements. The problems of designing castings for woodworking machinery are dealt with in the discussion.—E. T. L.

A "Novel" Design of a Hot Blast Cupola. E. Piwowarsky. (*Giesserei*, 1952, **39**, Jan. 10, 9). The author points out that 'novel' designs, now the subject of several patent applications, the essence of which is the bleeding of flue gases from the region of maximum temperature for heat-exchange purposes, have already been described by him in 1929.—J. G. W.

Improved Methods of Desulphurizing Cast Iron. J. Tucholka. (*Hutník* (Prague), 1952, **2**, 1, 17–20). [In Czech]. Details, predominantly in tabular form, are given of Russian methods of desulphurizing cast iron, with particular reference to the capacity and type of lining of the ladle.—P. F.

Swarf Melting in the Cupola. J. and E. Hall, Ltd. (*Found. Trade J.*, 1952, **92**, Mar. 20, 313–314). Two methods of remelting cast iron borings are described with particular reference to their cost. It is concluded that charging the swarf directly into the cupola is more economical than first briquetting it with cement, because the cost of the labour involved in the latter is more than that saved in decreased melting loss.—E. T. L.

Gray Iron Heat Conservation. R. A. Clary. (*Australian Found. Trade J.*, 1951, **3**, Dec., 3–7, 9). The author discusses in detail the precautions and techniques which may be used to prevent excessive temperature drops between furnace tapping and mould filling.—P. M. C.

The Use of Oxygen to Improve the Performance of a Cupola. L. I. Lewi. (*Liteinoe Proizvodstvo* 1951, No. 2: *Przeglad Odlewnictwa*, 1952, **2**, 1, 23–25). [In Polish]. A survey of practice (especially Russian) in oxygen enrichment of the blast for cupolas is given, and the improvement in their performance is described.—V. G.

Saving Coke in a Cupola. M. Czyzewski. (*Przeglad Odlewnictwa*, 1952, **2**, 2, 33–47). [In Polish]. The following problems of fuel economy in cupola operation are discussed: (1) General considerations regarding saving coke in cupola operation; (2) heat balance of a cupola; (3) properties of foundry coke and their influence on cupola performance; and (4) dependence of coke consumption on cupola practice.—V. G.

Basic Cupola Operation. J. P. Holt. (*Amer. Foundryman*, 1952, **21**, Jan., 39–43). **The Basic-Lined Cupola.** J. P. Holt. (*Foundry*, 1951, **79**, Dec., 92–95, 264–268: *Iron and Steel*, 1952, **25**, Mar., 95–97). The conversion of an acid-lined to a basic-lined cupola may necessitate the raising of the original tuyeres to provide for the appropriate thickness of slag. If the sulphur content of the iron must be less than 0·03%, it is advisable that there should be about 11 in. of slag on the metal; if a sulphur content of about 0·7% is permissible 6 in. will do. Magnesite brick backed by firebrick is used for the melting zone and well, whilst the inner faces of the basic bricks are covered with a mixture of dead-burned dolomite and stable dead-burned high-magnesia clinker. Refractory consumption in the melting zone above the tuyeres is about ½ in./hr. Patches of monolithic material 8 in. thick have been applied to cupolas operated for 17 hr. When patches 4 in. thick or more are made, it is best to have the cupola walls hot enough to dry out the patch. Several taphole materials are discussed, but the best consisted of a carbon-bonded silicon–carbide block with a 1-in. hole. Regular slag analyses, which are difficult, can be replaced by the careful inspection of fractured slag samples. Operating conditions, and successful desulphurizing and dephosphorizing in the basic cupola, are described.—E. J. D. S.

Stainless Steel Foundry Conserves Critical Alloys. G. C. Close. (*Steel*, 1951, **129**, Dec. 24, 58–59). To explore the possibilities of remelting scrap and casting stainless steels in the stabilized 18/8 and super-alloy grades using such scarce constituents as nickel, chromium, niobium, and tungsten, a foundry has been set up to operate with 75% scrap charges. Satisfactory castings are now being made even with such alloys as 321 stainless and better dimensional properties are obtained than with the former forged and welded parts.

A. M. F.

Silicon Chromium Alloy in Complicated Iron Castings. A. Clark. (*Trans. Amer. Found. Soc.*, 1951, **59**, 401–411). By examining samples of automobile cylinder castings in (1) an untreated iron, (2) a 0·28% nickel 0·23% chromium iron, and (3) irons, treated with silicon–chromium, containing 0·34% chromium and 0·51% chromium, it was revealed that the silicon–chromium-treated irons had a higher and greater uniformity in hardness and more uniform structure throughout the casting. Minor local variations in freezing and cooling rates resulted in variation in metallographic structure and hardness at closely adjacent areas.—R. L. B.

Nodule Genesis and Growth in Magnesium-Treated Hypo-eutectic Irons. R. P. Dunphy and W. S. Pellini. (*Foundry*,

1952, **80,** Jan., 82–86, 195–200). The origin and growth of hypoeutectic magnesium-treated irons have been studied by examination of specimens quenched at various stages of solidification. It was deduced that nodules of graphite develop in close proximity to dendrites during the final stage of austenite formation, immediately before the start of the eutectic reaction. Although these conclusions for magnesium-treated irons are tentative, it is considered from the experimental results that local pools of hypereutectic liquid existing because of supersaturation near the dendrites provide conditions for the genesis of nodules analogous to those in hypereutectic melts. Nodule growth is thought to result from malleablizing the ledeburite.—E. J. D. S.

Plastic Cast Iron. F. Vitovec. (*Betrieb u. Fertigung,* 1951, **5,** Nov., 181–187). Cast iron can be given strength and ductility either by plastic deformation at 905–1150° C. or by treatment with cerium or magnesium to produce a nodular graphite structure. Nodular iron is still further improved by heat-treatment or by plastic deformation while hot.—H. R. M.

The Contribution of Riser and Casting End Effects to Soundness of Cast Steel Bars. H. F. Bishop, E. T. Myskowski, and W. S. Pellini. (*Trans. Amer. Found. Soc.,* 1951, **59,** 171–180). The length of cast steel bar which can be made sound has been determined radiographically and related to thermal gradient conditions. For steels of 0·25–0·35% carbon, the maximum distance in inches which can be made sound follows an empirical rule given by $D_{max} = 6/T$, where T equals thickness. This holds for bars 2 to 6 in. thick, cast in the vertical or horizontal position. Due to convection current effects, vertical 8-in. bars can be made sound for a somewhat greater distance. Thermal analyses showed that a minimum gradient of 6 to 12 ft./in. is required to feed bars to complete soundness.—R. L. B.

Pit Practice. J. L. Jennings and G. McMillin. (*Amer. Inst. Min. Met. Eng.: Proc. Nat. O.H. Comm.,* 1951, **34,** 269–271). The authors outline the optimum conditions in the use of runners, ladles, stoppers, and nozzles which have been developed in the basic steel foundry of the General Steel Castings Corp., Granite City, Illinois.—G. F.

The Use of Heat-Radiating Feeder Head Inserts in the Teeming of Cast Steel. E. Lanzendörfer. (*Giesserei,* 1951, **38,** Dec. 27, 661–664). These inserts maintain the temperature of the melt and therefore the feeder heads can be made smaller. The inserts and their mode of action are described and results of experiments are quoted.—J. G. W.

Contribution to the Grain Formation of Steel Castings from Small Converters, and Their Annealing. F. Roll. (*Giesserei,* 1952, **39,** Jan. 24, 30–31). Results of investigations are discussed in which factors of the acid small converter steel casting process were studied as regards their influence on grain size. Variation of annealing temperature to suit various grains sizes was explored.—J. G. W.

Steel Refining in Tropenas Converters. M. Materny. (*Przeglad Odlewnictwa,* 1952, **2,** 1, 6–16). [In Polish]. Various aspects of steelmaking in side-blown converters are discussed.—V. G.

Factors Affecting the Quality of Cast Steel. T. N. Armstrong. (*Foundry,* 1951, **79,** Dec., 114–117, 207–208). The present trend of specifications for steel castings demands higher values of tensile strength, ductility, and impact strength than those for conventional castings. This has necessitated closer attention to the steelmaking practice, casting solidification, and impurity contents. For example, small additions of aluminium made during deoxidation adversely affect ductility, although this property is for the most part restored if aluminium is added slightly in excess, thereby providing a residual content. This behaviour is associated with the presence of iron oxide and the form and distribution of sulphides in the final structure. An excessive amount of residual aluminium may also reduce ductility by precipitation—probably of aluminium nitride—accompanied by grain-boundary cracks and a conchoidal fracture. Melting with a vigorous boil and a short time in the furnace after melt-down promotes low nitrogen absorption. The causes of casting density variations and their effects, and calcium and selenium additions are discussed.—E. J. D. S.

The Formulation and Interpretation of Steel Castings Specifications. E. Gregory. (*Eng. Insp., Special Convention* Number 1, 1951, **15,** Autumn, 98–108). The author, who is chairman of the committee responsible for the formulation of British Standards for steel castings, discusses the peculiar difficulties encountered in drawing up such material specifications. He deals with chemical composition, mechanical properties, and inspection methods and routine, and contends that any material specification should be regarded as a *guide* to inspection, rather than as a document which must be rigidly adhered to.—P. M. C.

Controlled Sand Produces Quality Castings. B. H. Booth. (*J. Inst. Australian Foundrymen,* 1949, **1,** 95–120). This is a very detailed article, which first describes the nature of sand and its production and method of use in the foundry. Types of sand and control tests are described, including the determination of moisture, permeability, green compression strength, clay content, and grain fineness. Sand practices at 11 American foundries are tabulated.—P. M. C.

Critical Considerations Regarding Standard Tests for Moulding Sands. W. Götz. (*Schweiz. Arch. Wiss. Techn.,* 1951, **17,** Aug., 225–251). Compression strength and porosity of moulding-sand specimens vary greatly with the amount of moisture in the sand, but published information on the nature of this variation is contradictory. The contradictions are shown to be due to different methods of compacting the test cylinders. Two standard test methods commonly used in Germany, the DIN 52 : 401 method and the 'GF' method introduced by Georg Fischer A.G., Schaffhausen, are found to be suitable, the compacting being similar to that occurring in actual moulds.—H. R. M.

Working with Synthetic Moulding Sand. H. Herschenz. (*Giesserei,* 1952, **39,** Feb. 7, 54–56). By working with synthetic sand with additions of 0·75–1·5% bentonite and a water content of 6–7%, a greater latitude is gained in the choice of the most suitable sand for green-sand moulds. A drawback, the deterioration of the sand, is admitted, but remedies are suggested.—J. G. W.

Sand for Use in the Steel Foundry. F. Fürbach. (*Giesserei,* 1952, **39,** Feb. 7, 61–62). The author discusses the properties of facing, filler, and burnt sand, and the various binders which are used to restore the properties of used sand.—J. G. W.

This Mold Wash Works with All Common Casting Alloys. R. E. Morey and C. G. Ackerlind. (*Amer. Foundryman,* 1952, **21,** Jan. 67–70). Trials have shown that a bentonite–dextrine–silica flour mould wash developed by the American Naval Research Laboratory gives excellent performance with all common ferrous and non-ferrous casting alloys, including steel, brass, bronze, aluminium, magnesium, and cast iron.

Metal Penetration. H. E. Henderson. (*Foundry,* 1952, **80,** Jan., 100–101, 245–247). Attention is drawn to the lack of practical applications of the results of investigations into the causes of metal penetration in cores and moulds.—E. J. D. S.

Study on Surface of Casting. IX. K. Katori, T. Okakura, and K. Hashimoto. (*J. Mech. Lab.,* 1951, **5,** Jan., 15–21). The surface roughness of cast iron produced in the Kausai area was measured, and is reported.—J. G. W.

Concerning Research on Core Binders. Z. Wertz. (*Przeglad Odlewnictwa,* 1952, **2,** 2, 52–58). [In Polish]. Green core strength and its changes during drying are described.—V. G.

Increasing Riser Efficency. J. O'Keeffe, jun. (*Trans. Amer. Found. Soc.,* 1951, **59,** 392–397). Riser efficiency can be improved by any method which will (*a*) prolong the time that the riser metal remains molten, or (*b*) increase the rate of solidification of the casting. Methods commonly used to ensure efficiency are: Use of circular risers to minimize riser surface area; use of chills in the mould to increase solidification rate; and gating the casting through the riser. Heat loss from the top surface of open risers should be minimized by using insulation or exothermic anti-piping compounds.

Connor-Block Feeder. H. London, D. Neill, and J. C. Dowie. (*Found. Trade J.,* 1952, **96,** Mar. 6, 243–247). Constructional details are given for making a Connor-block feeder and runner—a slit runner abutting on to the edge of a casting—by means of an oil-sand core. Examples are quoted of the application of this method in making a pinion blank, using a strickled mould, or dry sand.—E. T. L.

Side Risers Cut Cleaning Room Costs on Alloy Iron Castings. R. Chamberlin. (*Amer. Foundryman,* 1952, **21,** Jan., 33–36). The use of side risers and gates for alloy iron castings was found to reduce cleaning and fettling costs whilst top risering was not successful. Side risers and gates for several types of casting made in a small foundry are described.—E. J. D. S.

The Boxless Moulding Process. R. Weidner. (*Giesserei,* 1952, **39,** Jan. 24, 25–29). Following a description of the

process, the author gives data on output per man, and installation costs.—J. G. W.

Alternative Types of Coreprint. F. H. Wakeham. (*Found. Trade J.*, 1952, **92**, Mar. 6, 261–262). The author describes the making of various coreprints (cope and drag prints), joint or parting prints, tail, drop, or draw prints, balanced prints, and cover prints.—E. T. L.

Moulding in an Indian Foundry. S. G. Athanikar. (*Found. Trade J.*, 1952, **92**, Mar. 13, 271–277). The author describes how various large castings are made despite limited lifting and drying facilities.—E. T. L.

Centrifugal Casting of Ferrous Metals. C. K. Donoho. (*S.A.E. J.*, 1952, Jan., 60–67). Spinning speeds and the determination of interior surface shapes are dealt with, and information concerning moulds and mould materials is given. Types of steel which are commercially centrifugally cast are dealt with, and several examples of present-day techniques and capabilities are described.—P. M. C.

New Investment Casting, Foundry Features Latest Techniques. J. T. Andrews, jun. (*Machinist*, 1952, **96**, Feb. 16, 232–235). The new investment-casting foundry built by Watervliet Arsenal, Watervliet, N.Y., for the production of cannon components is described.—E. C. S.

Investment Casting Alloy Selection and Design. D. V. Ludwig and R. L. Wood. (*Product Eng.*, 1951, **22**, Nov., 184–190; *Machinist*, 1951, **95**, Dec. 22, 1931–1936). Alloy selection, design details, preformed cores, ribbed sections, and functional tolerances are discussed.—E. C. S.

Experiences with the Investment Casting Process. D. F. B. Tedds. (*Inst. Brit. Foundrymen: Found. Trade J.*, 1952, **92**, Mar. 20, 297–310: *Machinist*, 1952, **96**, Mar. 22, 419–425). After pointing out that initial claims for the process were exaggerated, the author describes, with many illustrations, fabrications made partly to test the process. He deals with the type of die required, wax-pattern production, moulding and investing, secondary investing, compacting, drying and firing, and casting and inspection.—E. T. L.

Investment Casting—Money-Saving Mass Producer. R. R. Miller. (*Steel*, 1952, **130**, Jan. 14, 58–59). A brief description is given of the investment-casting process as used at the Precision Metalsmiths Inc. For satisfactory results it is stressed that precision control of the furnace operating temperatures is important.—A. M. F.

Better Casting Methods Cut Forming Die Costs. (*Iron Age*, 1951, **168**, Dec. 20, 110–112). For making close-tolerance dies at the Northrup Aircraft Inc., patterns are made with expanding plasters and metal with predictable shrinkage characteristics. By this process dies as long as 4 ft. 6 in. have been reproduced with an overall dimensional stability within 0·020 in. of requirements. Costs of grinding and finishing air-frame forming dies have been reduced from 50 to 75%.—A. M. F.

The Lost-Wax Process in Practice. W. Heimann. (*Giesserei*, 1952, **39**, Jan. 10, 6–9). The author points to the rapid wartime development of this process for aircraft components and for high-speed steel tools. Finishing processes are described and the advantages of the lost-wax method are enumerated.

Metallurgy of Shell Molding. B. N. Ames, S. B. Donner, and N. A. Kahn. (*Amer. Foundryman*, 1952, **21**, Jan., 24–29). Mechanical properties and structures of various ferrous and non-ferrous experimental castings are presented, in order to evaluate the effects of plastic-bonded shell moulds, the backing-up materials, shell thickness, mould curing time, and metal pouring temperature.—E. J. D. S.

Resin Makers Push Croning Process. D. I. Brown. (*Iron Age*, 1951, **168**, Nov. 15, 120–121). Some examples of products made by the thin shell moulding process are given and the technique is discussed.—A. M. F.

Jobbing Foundry Adopts C-Process for Making Shell Molds. A. W. Calder, jun. (*Iron Age*, 1951, **168**, Nov. 15, 111–116). A shell moulding process for producing Meehanite castings is described. The moulding apparatus consists of two gas-fired cube-shaped ovens and a trunnion-mounted mould box to hold the phenolic resin-bonded sand. The pouring takes place on an annular ring 10 ft. in dia. divided into compartments. Within the mould face, tolerances of 0·002 in. to 0·003 in. per in. can be maintained.—A. M. F.

Problem Castings Can Be Turned into Production Jobs. T. J. McLeer. (*Iron Age*, 1951, **168**, Nov. 22, 86–89). The overcoming of distortion, shrinkage, and feeding difficulties of five difficult castings produced by a stainless-steel foundry is described.—A. M. F.

Centrifugal Casting—Manufacture, Properties and Application. P. A. Heller. (*Z.V.d.I.*, 1951, **93**, Dec. 11, 1098–1100). The principles of vertical and horizontal centrifugal casting are described, and the effect on the mechanical properties of cast steel, iron, and non-ferrous metals is discussed. Typical applications are listed.—J. G. W.

Centrifugal Casting. R. B. Whitelaw. (*J. Inst. Australian Foundrymen*, 1949, **1**, 121–138). The article covers a detailed study of centrifugally cast grey cast-iron sleeves. The spinning speeds are correlated with microstructure and chemical composition. The effect of structural segregation is shown, and it is demonstrated that casting defects are a product of incorrect spinning speeds and technique.—P. M. C.

Centrifugal Casting of Sewage Pipes. J. Piszak. (*Przeglad Odlewnictwa*, 1952, **2**, 1, 16–18). [In Polish]. The equipment for centrifugal casting of sewage pipes is described and the merits of this method are discussed.—V. G.

Casting 100,000 Valve Seat Inserts Daily. R. H. Herrmann. (*Foundry*, 1952, **80**, Jan., 76–81, 242–245). A detailed description is given of the methods used in the mass-production of alloy iron valve seats and other engineering components by Engineering Castings, Inc.—E. J. D. S.

Automatic Conveyorized Unit Used in Black-Light Inspection. (*Foundry*, 1951, **29**, Dec., 102–103, 225). The operation and efficiency of black-light inspection equipment with an automatic conveyor for handling the large output of castings at the Caterpillar Tractor Co., are briefly discussed.

Central Foundry Division of the General Motors Corporation, Saginaw, Michigan, U.S.A. (Brit. Cast Iron Res. Assoc.: *Found. Trade J.*, 1952, **92**, Feb. 21, 203–204). This malleable iron foundry pours 1600 short tons daily. The article describes working conditions and melting and annealing practices. Coreshop sand is bonded with fish oil or synthetic oil, and 98% of the cores are blown.—E. T. L.

Space Limitations Dictate Foundry Layout. H. Branders. (*Foundry*, 1952, **80**, Jan., 96–99). The layout of a foundry in Finland built on a long and narrow site is described.

Modern Foundry Methods. Equipment and Layout for Small Production Foundry. (*Amer. Foundryman*, 1952, **21**, Jan., 44–47). Notes on a visit to the foundry of Engineering Castings, Inc., Mich., by members of the Amer. Foundrymen's Soc., are presented and illustrated.—E. J. D. S.

Mechanical Equipment for Medium-Size Gray Iron Foundry. H. W. Zimnawoda. (*Trans. Amer. Found. Soc.*, 1951, **59**, 56–66). Mechanical equipment for production and material handling, employed in progressive jobbing grey-iron foundries, is discussed in the sections on core room, moulding, and melting. Proper layout of the selected units is emphasized.

Developments and Prospects in the Field of Foundry Mechanization. E. Knipp. (*Giesserei*, 1952, **39**, Jan. 10, 2–6). The author discusses means of reducing handling costs by shortening distances, mechanizing transport, and reducing quantities of materials handled. He considers the use of permanent moulds, and describes machines.—J. G. W.

Mechanized Foundry. (*Elect. Rev.*, 1951, **149**, Dec. 14, 1214–1215). The mechanized foundry of Smith and Wellstood, Ltd., makers of cookers and heating stoves, is described. Thirty-six Brook motors, surface cooled, ranging from 0·33 to 15 h.p., are incorporated for motive power. Plant control is outlined.—H. D. W.

Higher Productivity in the Foundry. (*Australian Found. Trade J.*, 1952, **3**, Jan., 17, 18). Efficient dust control, and better general factory layout and conditions, together with the increased use of automatic handling equipment have increased productivity by about 50% at one particular foundry.—P. M. C.

About the Mechanism of the Influence of a Preliminary Quenching on the Velocity of Graphitization of Cast Iron. K. P. Bunin and N. M. Danil'chenko. (*Doklady Akademii Nauk, S.S.S.R.*, 1952, **82**, 3, 381–383). [In Russian]. The kinetics of graphitization of differently pretreated white cast iron were investigated in order to evaluate the influence of preliminary quenching.—V. G.

Chill Tests and the Metallurgy of Gray Iron. D. E. Krause. (*Trans. Amer. Found. Soc.*, 1951, **59**, 79–91). Much of this paper constitutes a report of the activities of the Chill Test Committee of the American Foundrymen's Society in developing a standardized design of wedge test. The sensitivity of the test can be increased by decreasing the acute angle of

the wedge without appreciably changing the chill value. Chill tests appear better suited to very soft irons than wedge tests, but the latter are better adapted to the harder irons. The effect of iron composition, melting practice, and ladle additions on the chilling tendencies of grey iron is discussed. Chilling tendency increases with decreases in carbon and silicon contents. As melting conditions become more strongly oxidizing, chilling tendency increases.—R. L. B.

Kinetics of Graphitization in Cast Iron. B. F. Brown and M. F. Hawkes. (*Trans. Amer. Found. Soc.*, 1951, **59,** 181–200). The morphology and kinetics of the graphitization reactions in cast irons are discussed. In first-stage malleablizing, the rate of growth of flakes was found to decrease parabolically with time and to increase with the temperature of reaction. The nucleation rate increased progressively faster with time and also increased with temperature. The two rates are interdependent, and it appears that an alloying element which increases the overall graphitization rate increases the nucleation rate in proportions such that the rate of growth of individual nodules is slower than that for unalloyed iron. The eutectoid decomposition of austenite to graphite and ferrite and of austenite to pearlite was studied in nodular iron. A possible mechanism for the effects of alloying elements on graphitization rates is suggested.

Solidification Process of Cast Iron. I. Igarashi, G. Ôhira, and T. Horigome. (*Technology Reports, Tôhoku University*, 1951, **15,** 2, 56–67). [In English]. Solidification of slow and rapidly cooled iron–carbon and aluminium–silicon alloys was compared experimentally, both alloys being hypoeutectic. For slow cooling the process is the same for the first two alloys; primary dendrites appear first, next the Sasanoha structure, and the secondary phase crystallizes out on the axes of the latter.—J. G. W.

New Type of Graphitization of Cast Iron Cooled through the Eutectoid Range. K. Iwase and I. Aoki. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Oct., 139–142). An analogy is drawn between the bull's eye structure found in malleable cast iron and the abnormal structure in steel previously described by the authors. Austempering of fully graphitized cast iron after reheating confirmed and helped to explain the recently adopted method of producing black-heart malleable cast iron by slow cooling rather than by prolonged annealing.

Ill Effects and Usefulness of Gases in Metallurgy. E. Spire. (*Trans. Amer. Found. Soc.*, 1951, **59,** 201–209). The ill effects in metals of gases, such as hydrogen and nitrogen, are reported. Inert gas flushing is a good method for removing hydrogen dissolved in molten metals. A ladle has been developed in which gases can be introduced through a porous refractory material. The ladle can also be used for metallurgical treatments where mechanical agitation is desired.—R. L. B.

An Apparatus for Recording the Movement of Metal in Foundry Moulds. (*Przeglad Odlewnictwa*, 1952, **2,** 1; *Biuletyn Informacyjny Glownego Instytutu Odlewnictwa*, No. 1–2, 2–3). [In Polish]. An apparatus for the recording of movement of metal in a mould is described.—V. G.

Gray Iron Fluidity Variables—Effect of Composition and Pouring Temperature. L. F. Porter and P. C. Rosenthal. (*Amer. Foundryman*, 1952, **21,** Jan., 53–59). A spiral test mould, modified to give a mean deviation of less than 2·0% in duplicate tests, was used to determine the effects of temperature and metal composition on the fluidity of cast irons. Some of the tests were conducted to provide data on the effects of individual elements. The following tentative formula:

$$\text{Fluidity (in inches)} = 4C + 1Si + 2P + \frac{5\,(\text{superheat in °F.})}{100} - 6.$$

was derived.—E. J. D. S.

Classification of Defects of Steel Castings. (*Przeglad Odlewnictwa*, 1952, **2,** 1, 19–21). [In Polish]. The classification of defects in steel castings, proposed by the Steel Casting Committee of the Foundry Department of the Academy of Mines and Smelting in Krakow is given.—V. G.

Eye Conservation in the Foundry. B. Melnitsky. (*Foundry*, 1951, **79,** Dec., 98–101, 268). The frequency of eye injuries in the foundry is six times as great as that for industry as a whole. The use of goggles, eye-protectors, medical services, and industrial propaganda to ensure the use of protective measures is discussed.—E. J. D. S.

HEATING FURNACES AND SOAKING PITS

Furnace Practice and Design. K. F. Bray. (*Metal Treatment and Drop Forg.*, 1952, **19,** Jan., 33, 34). A report is being prepared by Powell Duffryn Technical Services, Ltd., on furnace practice and design in representative works. The author briefly comments on this report which covers burner design, heat wastage and conservation, and fuel consumption.

Furnacemen and Supervision of Gas-Fired Industrial Furnaces. W. Gebicki. (*Hutnik* (Katowice), 1952, **19,** 1, 15–22). [In Polish]. Some problems connected with the operation of gas-fired industrial furnaces are discussed.—V. G.

Reheating and Heat-Treatment Facilities at Hadfields' New Forge. (*Metal Treatment and Drop Forg.*, 1951, **18,** Dec., 572–574). The modern heavy forge at Hadfields Ltd., Sheffield, comprises 2700 and 1500 tons capacity Loewy presses with full reheating and heat-treatment facilities. The plant will handle ingots up to 45 tons in weight. Particulars of all the plant are given in this short article.—P. M. C.

The Heating of Rounds for Piercing. W. Trinks. (*Indust. Heating*, 1951, **18,** Nov., 2023–2036). The Siemens regenerative furnace can produce a uniform temperature in the round bar but is seldom used for economic reasons. The sloping-hearth furnace is most widely used and produces very uniform heating if properly designed with 40% front-firing and 60% side-firing, giving a fuel consumption of $1{\cdot}7 \times 10^6$ B.Th.U. per short ton. The rotating-hearth furnace has a high heat consumption ($2{\cdot}6$–$3{\cdot}0 \times 10^6$ B.Th.U. per short ton) and is difficult to maintain. The fourth type of equipment consists of a number of furnaces in series; labour costs are low; and fuel consumption is $3{\cdot}0$–$3{\cdot}5 \times 10^6$ B.Th.U. per short ton.

End-Welded Collar Studs Increase Reheat Furnace Availability. R. C. Singleton. (*Iron Steel Eng.*, 1952, **29,** Jan., 152–157). The author describes a method of welding studs to the iron-bearing surfaces of skid tubes in reheating surfaces. The skid tubes are water cooled and the studs serve to hold the refractory material in place. The advantages obtained from cooled skid tubes and the rapid method of welding on the studs are discussed.—M. D. J. B.

Effect of Track Time on Soaking Pit Heating. J. R. Chegwidden. (Amer. Iron Steel Inst.: *Iron Steel Eng.*, 1951, **28,** Dec., 53–57; *Indust. Heating*, 1951, **18,** July, 1217–1222, 1322–1324; Aug., 1405–1414; *Blast Furn. Steel Plant*, 1951, **39,** June, 665–670). An analysis of all operations included in the measurement of track time, leads to proposals to ensure that required rolling temperatures are in fact obtained. The operations analysed are: Open-hearth tapping and holding time, teeming and solidification, stripping, and transport of ingot, or exposure to the atmosphere. The author suggests that good track time is vital to economic soaking-pit operation and concludes that knowledge of ingot solidification time and an efficient transport system are essential. Experimental technique is described including the methods adopted in eliminating variables.—M. D. J. B.

Application of Precast Insulation to Water-Cooled Supports in Underfired Furnaces. J. E. Hovis. (*Iron Steel Eng.*, 1951, **28,** Nov., 69–72). The problems occurring in underfired furnaces due to heat loss in water-cooled support pipes coupled with the effect of cold surfaces located in close proximity to hot steel are examined in detail. The estimated comparative performance of insulated supports *versus* non-insulated supports is considered. The author suggests that precast insulation can mean up to 20% overall fuel saving, 10% increased production, and a solution to non-uniform heating, slagging, sticking, and skid-mark problems.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Progress in Heat Treating and Furnaces in 1951. H. E. Boyer. (*Steel Processing*, 1951, **38,** Jan., 17–19, 34–37, 49). General trends in furnace design are discussed, and the following topics receive particular consideraton: Atmospheres for tempering; steam tempering; heat-treatment of stainless steels; carbon control; pack carburizing; and quenching oils.

The Dow Atmosphere Furnace. F. E. Harris. (*Metal Treating*, 1952, **3,** Jan.–Feb., 2, 3). A very brief description is given of the Dow gas cyaniding furnace, in which small parts are loaded in baskets, mechanically moved into the heating chamber, heated with forced circulation of artificial atmosphere, and mechanically moved into a quenching bath.

Holcroft Batch Type Furnace for Controlled Atmosphere Heat Treating. W. H. Holcroft. (*Metal Treating*, 1952, **3,** Jan.–Feb., 3, 4). The furnace, which is fully automatic, may be used for clean hardening, drawing, carbon restoration, case carburizing, or carbonitriding. The unit is described

and illustrated ; it comprises furnace chamber, vestibule, and quench tank.—P. M. C.

Forced Air Circulation for Low-Temperature Heat-Treatment. (*Sheet Metal Ind.*, 1952, **29,** Feb., 124–126). A typical furnace, produced by Wild-Barfield Electric Furnaces, Ltd., for heat-treatment at temperatures up to 700° C. is described and illustrated.—P. M. C.

The Surface Hardening of Steel. G. T. Colegate. (*Metal Treatnemt and Drop Forg.*, 1951, **18,** Jan., 5–12 ; Feb., 63–70 ; Mar., 103–110, 118 ; Apr., 163–170 ; June, 249–256 ; July, 317–322 ; Aug., 363–368 ; Sept., 419–425 ; Oct., 469–475 ; Nov., 507–514 ; Dec., 549–556 ; 1952, **19,** Jan., 35–42). Part 1 is an introductory résumé of case-hardening methods. An appraisal of case thickness achieved by carburizing, nitriding, cyaniding, and flame and induction hardening is given. The mechanism of the carburizing process, and the effect of grain size and alloying elements on the rate and depth of carburization are considered in Part 2. The different practices employed in heat-treating the steel before and after carburizing, and their effects are also examined. Part 3 surveys the effect of time and temperature of treatment on the depth of case in pack carburizing, and describes the causes of exfoliation and the formation of soft spots. Carburizing compounds are dealt with, taking into account retarding admixtures and the mechanism of reactivation and of energizers. Available materials and designs for containers are dealt with in Part 4, and the advantages of paste carburizing, and different methods of packing components are described. Furnaces and efficient furnace utilization are discussed. Gas carburizing is considered in Parts 5 and 6, the effect of various media, including the oxides of carbon, hydrocarbons, and non-carbonaceous gases being dealt with. The problem of sooting, the potentialities of commercial gas-carburizing atmospheres, and the functions of diluents are reviewed. Parts 7 and 8 deal with the nitriding process, the following topics being considered : the iron–nitrogen system ; steels suitable for nitriding ; the influence of alloying elements ; the preparation and condition of the surface ; the dissociation and rate of flow of ammonia ; time and temperature ; and dimension changes. The advantages and disadvantages of nitriding compared with other case-hardening processes are discussed in Part 9, and the principles and practices of cyaniding are surveyed. Part 10 deals with the influence of both composition and after treatment on the properties of a cyanided case. Special processes, including Chapmanizing, dry-cyaniding, and the Ni-carb process are described. The last two articles deal with flame and induction hardening respectively. The techniques and the influence of steel composition on the depth of hardening are described, and comparisons are made with treatments described earlier. (78 references).—P. M. C.

Heat Treating of Tools and Dies Featured at Patton Manufacturing Co. (*Indust. Heating*, 1951, **18,** Dec., 2194–2206). The heat-treating facilities consist of 11 hardening and four tempering furnaces. Close control is maintained and furnace temperatures are continuously observed and regulated by indicating controllers. Several types of furnace are used including Cox, gas-carburizing, pack-carburizing, cyaniding, and the salt bath. Quenching is carried out with an oil tank maintained at 90–120° F. and a water tank at 70° F. Details of the operation of the furnaces and the type of work carried out in each are given.—B. G. B.

Heat Treatment of Metals. C. B. Mershon. (Amer. Gas Assoc. : *Indust. Heating*, 1951, **18,** Sept., 1576–1584 ; Nov., 2002–2006). The general principles of heat-treating, the operations of heat-treatment, and the equipment used are discussed. Various furnace types and methods are described, including cooling, tempering, annealing, normalizing, spheroidizing, quenching and tempering, patenting, austempering, carburizing, nitriding, and flame-hardening.—J. A. L.

Prepared Atmospheres—Their Generation and Application. C. G. Segeler. (Amer. Gas Assoc. : *Indust. Heating*, 1951, **18,** Oct., 1788–1792, 1891–1896 ; 1952, **19,** Feb., 226–234, 244). The generation and composition of prepared atmospheres used for various industrial operations, and the application of these atmospheres and the results obtained with them, are discussed. Methods of anticipating difficulties in the use of prepared atmospheres and the effects of introducing other gaseous fuels such as oil gas and mixtures of oil gas and natural gas are also dealt with.—J. A. L.

The Application of Various Thermal Treatments to the Improvement of Constructional Steels. A. Sourdillon. (*Études Document Mét.*, 1951, Oct., Doc. 113–128). Heat-treatments for improving the machinability of steels, improving the mechanical characteristics, producing favourable residual strains, and reducing deformities resulting from machining are described and discussed in detail. (35 references).

Hardening with Isothermal Treatment of Grey Iron in Order to Increase Its Abrasion Resistance. M. M. Kantor, A. P. Kulikov, and E. P. Iwaniuszin. (*Vestnik Mashinostroeniya*, 1951, No. 2 ; *Przeglad Odlewnictwa*, 1952, **2,** 2, 62–63). [In Polish]. The influence of methods of hardening and heat-treatment on the properties of grey iron were investigated. The optimum conditions of isothermal treatment and quenching to obtain the required hardness (270–310 Brinell) and the best resistance to abrasion were established.—V. G.

Salt Bath Quenching of High Speed Steel. W. E. Peterson. (*Metal Treating*, 1952, **3,** Jan.–Feb., 5, 11). The technique developed at the Gorham Tool Co., Detroit, is described. An alkali chloride salt, containing calcium, barium, sodium, and potassium chlorides is used for quenching.—P. M. C.

Study on Heat Treatment of Parts of Bicycle Chain. E. Hayashi and S. Demachi. (*J. Mech. Lab.*, 1951, **5,** Aug., 131–134). [In Japanese]. According to existing Japanese standards for exported bicycles, the depth of the carburized skin of chain plates should be 0·3 mm. The authors recommend the adoption of a case depth greater than 0·35 mm.—J. G. W.

Use of Hydrocyanic Acid in Case-Hardening. A. Stähler. (*Z. V.d.I.*, 1951, **93,** Dec. 11, 1093–1097). An account is given of case-hardening experiments with a variety of materials, which showed cyanide to be superior to ammonia and carburizing oil as well as to salt-bath and box cementation. The cyanide-hardened specimens were of more uniform hardness and had better wear resistance.—J. G. W.

Surface Hardening with Town Gas and Oxygen. (*Engineering*, 1952, **173,** Feb. 29, 268–269). **Automatic Control of Oxygen–Town's-Gas Flame Hardening.** (*Engineer*, 1952, **193,** Feb. 29, 306–308). These articles describe a flame-hardening process, in which the same amount of oxygen as in the oxy-acetylene method is used with town gas at a pressure of 4·2 lb./sq. in. to provide a flame of ample intensity for surface-hardening purposes. The process depends largely for its efficiency upon the rapid and accurate control of the temperature to which the surface of the metal is heated.—M. D. J. B.

New Equipment Permits Use of Natural or Artificial Gas in Flame Hardening. H. W. Groenegress. (*Metal Treating*, 1952, **3,** Jan.–Feb., 6–8). The author describes newly developed German machines and burner designs which are being used in conjunction with natural and artificial gases. The hardening of automobile parts, armour plate, gears, and lathe beds is considered briefly.—P. M. C.

Flame Hardening Proves Versatile Heat Treating Method. S. Smith. (*Iron Age*, 1951, **168,** Nov. 22, 96–98). Methods of flame-hardening and special machines used by the National Forge and Ordnance Co. are described. Some figures are given to show how the surface temperature and depth of hardening are controlled by co-ordination of gas flow, speed of burner travel, and speed of rotation of the work.—A. M. F.

Flame Softening in Metal Fabricating Industries. W. B. Sharav. (*Steel Processing*, 1951, **37,** Dec., 599–602, 613). The rapid cooling which follows oxy-acetylene flame cutting, often causes undesirable hardness to develop along the cut faces. The author describes how this hardening may be reduced by auxiliary heating, double-cutting, or by direct-heating methods. Equipment and various typical applications are described.—P. M. C.

Induction Heater for Surface Hardening of Shafts. (*Engineering*, 1952, **173,** Feb. 29, 286–287). This article describes a high-frequency induction heater (by Birlec, Ltd., Birmingham), designed to surface-harden certain types of steel shaft. The machine obtains its power from a valve oscillator rated for a continuous output of 25 kW. at a frequency of about 350,000 cycles/sec. It is claimed that the machine introduces new heat-treatment possibilities which are virtually unobtainable by other means.—M. D. J. B.

RF Heating Pays Off in Components Production. (*Steel*, 1951, **129,** Dec. 17, 97–98). Examples are given of the radio-frequency induction hardening of transmission gears and thrust collars. Advantages claimed are a very low scrap rate, close control of the hardness pattern and practically negligible distortion.—A. M. F.

Mechanized Heat Treatment Points to New Goals in Costs

and Quality. A. H. Allen. (*Metal Progerss*, 1952, **61,** Jan., 68–71). The advantages of induction heating, as a means of lowering labour costs and increasing output for hardening, heating, and joining of metals are reviewed. Carburizing processes and quenching practices are discussed.—J. P. S.

Continuous Bright-Annealing Furnace. (*Engineering*, 1952, **173,** Feb. 15, 223). A description is given of a continuous town-gas-heated belt-conveyor furnace using hydrogen as a medium for bright annealing small parts for the telephone and radio industries. The plant was designed, built, and installed by the Dowson and Mason Gas Plant Co., Ltd. The installation can anneal 80 lb. of components per hour. At a temperature of 800° C. the gas consumption is 300 cu. ft./hr.

Coil Annealing. L. Wilson. (*Iron Steel Eng.*, 1952, **29,** Feb., 66–72). The author compares multiple-stack annealing furnaces with the single-stack type and suggests that the portable base single-stack cover, in every case, has a lower first cost, lower fuel costs, and equal labour costs. He maintains that, because of variations in coil size and better control, the single-stack annealing furnace gives better quality. These statements are substantiated by technical and operating data.—M. D. J. B.

Annealing Steel Strip. (*Metal Treatment and Drop Forg.*, 1952, **19,** Jan., 13, 14). The annealing plant at both the Abbey and Trostre works of the Steel Company of Wales, Ltd., is described. The former, consisting essentially of 12 ' lift-off ' furnace units, has a capacity of 7000 tons per 168-hr. week ; the latter, consisting of 5 eight-stack cover furnaces, is designed for a capacity of 5250 tons of 15,000-lb. coils per week. The methods of firing and atmosphere control are described.—P. M. C.

Step Quenching, Hot Peening Improve Lean Alloys. R. F. Harvey. (*Iron Age*, 1951, **168,** Dec. 27, 70–71). This article describes the effects of shot peening in the hot condition to increase the conversion from austenite to martensite when hardening tool steel. An oil-hardened tool steel was quenched from 1500° F. in a 500° F. salt bath. There it was held above the temperature of martensite formation for a period insufficient for transformation of the austenite ; hot peening then produced a hardness of Rockwell C 84·4 with no cracking or weakening.—A. M. F.

Tempering Alloy Tool Steel after High-Frequency Hardening. I. N. Kidik. (*Stanki i Instrument*, 1950, No. 5, 22–23). [In Russian]. In the experimental work described, the effect of tempering conditions on the hardness and impact strength of specimens of two chromium tool steels, previously subjected to high-frequency hardening, was studied. The use of higher rates of heating in this hardening method resulted in higher specific impact energy but somewhat lower hardness at all temperatures of tempering.—S. K.

FORGING, STAMPING, DRAWING, AND PRESSING

Duration and Efficiency of the Impact in Forging. A. Geleji. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1,** 3, 299–317). [In German]. The kinetic energy of the hammer in forging is transformed on impact into useful work of plastic deformation and into losses associated with the elastic deformation and possibly vibrations of the base supporting the anvil. Three cases are analysed ; (1) A plastic mass is deformed by the simultaneous impact of two freely moving bodies which hit it axially from opposite directions ; (2) the case in which the anvil is treated as a static elastic column of infinite length ; and (3) the case in which the anvil is replaced by a flat-surfaced semi-infinite elastic medium. The duration of the impact is determined in each instance, and the energy dissipated in the base is calculated. From this the efficiency of energy transfer to the forged object is derived.—P. F.

Contribution to the Construction of Steam Hammer Controls. E. Kiss. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1,** 3, 165–182). [In German]. A simple mathematical method of calculating the performance of steam hammers in terms of impact energy, impact frequency, and steam consumption is presented. Steam supply, the principles of control, and the correct design of the control system are discussed and an example of the method is shown. The theoretical data agree well with those obtained in practice.—P. F.

What's Happening in the Forging Industry ? J. C. McComb. (*Steel Processing*, 1951, **38,** Jan., 20–22). Brief details are given of the development of the heavy press programme in the U.S.A.—P. M. C.

Manufacture of Gas Turbine Blades. H. W. Kirkby. (*Metal Treatment and Drop Forg.*, 1952, **19,** Feb., 61–66). Metal alloys suitable for both short-life (aero-engine) and long-life gas turbines are reviewed. The forging of blades, and their heat-treatment and testing are also described.—P. M. C.

Metallurgy of Drop Forging. E. Gregory. (*Metal Treatment and Drop Forg.*, 1952, **19,** Feb., 67–72). Steel quality, and its effect on the ' cleanliness ' and grain flow of finished forgings are discussed, and the troubles associated with overheating and burning are considered. Maximum forging temperatures, and the possibility of correcting overheating by heat-treatment, are also dealt with.—P. M. C.

Small Drop Forgings. H. A. Whiteley. (*Metal Treatment and Drop Forg.*, 1952, **19,** Jan., 20–26). Products weighing as little as $\frac{1}{8}$ oz. can be successfully made by drop forging. The specialized knowledge and skill required are exemplified by the Victoria Drop Forgings Co., Ltd., of Willenhall, whose techniques and products are described and illustrated. The preparation of dies, their heat-treatment, and the design of clipping tools are dealt with.—P. M. C.

Quality Control Charts Boost Forge-Shop Performance. R. D. Long. (*Machinist*, 1951, **95,** Dec. 29, 1970–1971). Longer die life, lower forging cost, and higher quality, result from quality control charts which help employees find solutions to forging difficulties.—E. C. S.

Some Outstanding European Die-Making Techniques. F. Strasser. (*Steel Processing*, 1951, **37,** Dec., 614–616, 637). The author presents some interesting differences between American and European cutting-die design and die-building technique. Punch guides and automatic stops are the main topics discussed.—P. M. C.

Die Life and Die Typing. H. A. Wallace. (*Metal Treatment and Drop Forg.*, 1951, **18,** Dec., 559–563). The author describes the ' hobbing ' method of producing drop-forging dies. Instead of the impression being milled out, it is forged into the die block by a specially made ' hob,' similar in shape to the part to be forged by the die. Dies made by this method are claimed to have a longer life than those sunk in the conventional manner.—P. M. C.

Press Brakes and their Applications—4. N. C. Wilson. (*Welding Metal Fab.*, 1952, **20,** Jan., 22–24). A description of different types of operator's guard which have proved to be an effective safety device covering a wide range of operations is given.—U. E.

Stainless Fabricating Methods Successfully Form Titanium Sheet. (*Steel*, 1951, **129,** Dec. 17, 94–95). Methods used to form stainless-steel sheet are being applied successfully to titanium. Closer tolerances are usually required for titanium parts than for stainless because excessive springiness makes mating more difficult. In the fashioning of some intricate shapes both alternate cold-forming and annealing and hot-forming have been tried with good results.—A. M. F.

Large Stamping Plant Features Mechanization. G. Elwers. (*Iron Age*, 1951, **168,** Dec. 20, 100–102). At the Fisher Body's Hamilton plant maximum use has been made of automatic loading, unloading, turnover, and other handling devices. On continuous press lines for large door panels, for example, no operator has to lift, turn, or invert a panel.

Producing Aircraft Parts by Hydroforming. G. B. Lewis and J. S. Corrall. (*Machinery*, 1952, **80,** Jan. 24, 160–164). The authors deal with the ' Hydroform ' hydraulic press, developed by the Cincinnati Milling Machine Co. and used by North American Aviation, Inc., in the production of sheet-metal parts for aircraft.—E. C. S.

Controlled Pressure Aids Deep Drawing. W. M. Stocker, jun. (*Machinist*, 1952, **96,** Jan. 19, 84–88). Two processes for producing a variety of sheet-metal parts in relatively small lots are described. They are ' Marforming,' developed by the Glenn L. Martin Co. and manufactured and sold under licence by Hydropress, Inc., and ' Hydroforming ' developed by the Cincinnati Milling Machine Co.—E. C. S.

High Speed Presswork Calls for More than High Speed Presses. J. A. Grainger. (*J. Inst. Prod. Eng.*, 1952, **31,** May, 230–247 ; *Machinist*, 1952, **96,** Jan. 12, 37–44). This article reviews methods and equipment which contribute to increased productivity in the press shop.—E. C. S.

Mechanical Hand Speeds Press-work and Provides Greater Safety for Operators. (*Machinist*, 1951, **95,** Dec. 29, 1972–1974). A mechanical-hand device which is marketed by the Press Equipment Co., Birmingham, is described. Automatic

feeding at rates up to 4000 to 5000 pressings per hour on second-operation presswork is claimed for this device.—E. C. S.

The Manufacture of Seamless Steel Tubing in Australia. J. Porteous. (*Proc. Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 181–203). An outline is given of different methods of rotary and non-rotary piercing operations with their accompanying processes of elongation. The history and principles of the push-bench process are described.

An Investigation of Shell Forging Methods. W. Trinks. (Amer. Soc. Mech. Eng.: *Steel Processing*, 1951, **37,** Dec., 603–609). The author discusses the adaptation of upsetters and bulldozers for use as shell-forging machines. The pierce-and-draw, and cross-rolling processes are described. The application of the newly developed cold-extrusion process is also reviewed.—P. M. C.

Theoretical Analysis of the Drawing of Sheet Metal. I. A. Noritsyn. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, No. 11, 1696–1703). [In Russian]. The strained state of drawn sheet metal is expressed by a general differential equation. The solution of this equation provides a means of deriving formulæ for the determination of specific pressure of flow on the first and subsequent stages of the process.—V. G.

Coating Improves Forming Operations. (*Iron Steel Eng.*, 1951, **28,** Dec., 127–129). This article describes a protective phosphate coating called 'Granodraw' which makes possible the cold extrusion of steel. Hitherto the great pressures required in most forming operations caused destructive frictional contact between die and metal.—M. D. J. B.

Surface Treatment for Cold Extrusion. A. Bregman. (*Metal Progress*, 1951, **60,** Dec., 76–79). For cold extrusion it has been shown that phosphate coating of a thickness of at least one 1 g./sq. ft. in combination with a dilute emulsion-type lubricant produced the best frictional conditions and eliminated pick-up on the work. For the cold extrusion of steel it is necessary to apply a coating that is resistant to temperatures of 750–1100° F. and is sufficiently thick to ensure complete separation of the sliding metal surfaces. Zinc phosphate coating meets these requirements.—J. P. S.

A Study of Tracer Methods for Assessing Wear of Wire-Drawing Dies. J. C. E. Button, A. J. Davies, and R. Tourret. (*Nucleonics*, 1951, **9,** Nov. 34–43). A technique is described for measuring the amount of wear in wire-drawing dies by irradiation of the tungsten carbide from which the dies are made. The assessment of the activity of the wear debris is carried out by autoradiography. The winding of the wire with adhering debris into a helix round a Geiger-Müller tube is shown to permit quantitative measurements to be made.

Control of Die Profiles by Measurement of Die Load and of Partly Drawn Wire. J. G. Wistreich. (*Wire Ind.*, 1952, **19,** Feb., 131). The author concludes from an investigation jointly undertaken by B.I.S.R.A. and British Insulated Callender's Cables, Ltd., that neither the 'wire-bearing' nor the 'die-load' inspection methods can be relied upon as a check on die profile.—J. G. W.

Patenting Steel Wires by High-Frequency Induction Heating. L. Gillemot and I. Koncz. (*Acta Technica Academiae Scientiarum Hungaricae*, 1950, **1,** 1, 50–77). [In German]. In conventional patenting steel wires are heated to about 900° C. in long furnaces while on their way to the lead bath. A new method is described whereby the wires are preheated by high-frequency induction. The theoretical development of the induction-heating coil and its performance as checked in actual operation in steel wire patenting are described, and the advantages attainable are discussed.—P. F.

Locked-Coil Rope Production. (*Wire Ind.*, 1952, **19,** Jan., 63–65). The process of producing shaped wire for locked-coil ropes is described and the use of back pull is mentioned as a means of avoiding change in gauge and shape.—J. G. W.

A Universal Classification for Wire Sizes and Gauges. (*Wire Production*, 1952, **1,** Jan. 6–9, 23). Having enumerated and described the large variety of wire gauges in use, the author points to the merits of simplification and recommends that a metric gauge with arithmetic progression be adopted. He suggests that the diameter in microns should serve as gauge number.—J. G. W.

ROLLING-MILL PRACTICE

Calculation of the Resistance to Deformation and Power Requirements in Rolling. A. Geleji. (*Acta Technica Academiae Scientiarum Hungaricae*, 78–109). [In German]. The paper contains further developments regarding the author's theory of rolling (*see J. Iron Steel Inst.*, 1948, **160,** Oct., 225). It is shown that slip must take place between the compressed metal and the roller surfaces. Forces involved and power requirements are evaluated on the basis of the relative cycloidal motion between the rolls and the rolled metal. Power is required for the work of deformation and to overcome friction along the contact surfaces. The mean resistance to deformation is defined by the (roll pressure)/(contact area) ratio, and an expression is derived with which it can be evaluated. This mean resistance already contains the frictional work done in the roller–metal contact region, so it should not be included when calculating power requirements. Formulae are derived, on considerably simplified models, for the roll-torsion moments and power expenditure, and both must be multiplied by a correction factor which is shown to depend upon the reduction per pass. If, however, rolling is done with grooved rolls, additional friction, not included in the mean resistance to deformation as defined above, arises, so that additional power is required. The magnitude of this frictional work is evaluated in a simple manner for some grooved rolls. This calculation also gives the magnitude of the resistance to deformation, so that the total power requirements with grooved rolls can be determined.—P. F.

Loadmeter for Industrial Mills. R. B. Sims, J. A. Place, and A. D. Morley. (*Engineering*, 1952, **173,** Jan. 25, 116–119; Feb. 1, 137–139). A detailed description is given of a loadmeter for industrial mills developed by B.I.S.R.A. This meter does not increase the mill spring materially; it gives an accurate measure of the load independent of temperature changes, and is sufficiently robust to withstand, over long periods, the arduous rolling-mill conditions. The loadmeter consists of a solid cylinder of steel, placed between the loading screw and the top roll bearing. A measure of the load applied is obtained from the output of an unbalanced temperature-compensated Wheatstone network of electric resistance strain gauges bonded to the surface of the cylinder. Technical and operating details are given.—M. D. J. B.

Rolling Characteristics of Various Steels. E. M. D. Herold. (*Iron Steel Eng.*, 1952, **29,** Jan., 55–60). The author discusses the effects of carbon, manganese, silicon, nickel, chromium, molybdenum, vanadium, tungsten, and cobalt on the rolling characteristics of alloy steels and the manner in which various steels act between rolls when heated and rolled into round and square merchant bars.—M. D. J. B.

Rolls and Rolling. E. C. Brayshaw. (*Blast Furn. Steel Plant*, 1950, **38,** May, 529–540, 581, 583, 586; June, 666–673; July, 792–803; Aug. 917–927; Sept., 1050–1060; Oct., 1174–1182; Nov., 1323–1329; Dec., 1435–1446; 1951, **39,** Jan., 93–104; Feb., 214–222; Mar., 343–350, Apr., 439–444, May, 553–560; July, 800–812; Aug., 958–966; Oct., 1224–1234; Nov., 1354–1357; 1952, **40,** Jan., 82–88). Continuation of a series of articles (*see J. Iron Steel Inst.*, 1951, **168,** June, 194). This comprehensive series of articles deals with the rolling of rods, beams, channels angles, bulb angles, **Z**-bars, **T**-bars, and rails.—J. P. S.

New Rolling Method Eliminates Surface Defects. N. C. Rendleman. (*Iron Age*, 1951, **168,** Nov. 15, 122–124). The reduction of surface defects has been tried experimentally by the diamond and square rolling method. Blooms 6 × 6 in. of two Bessemer grades notorious for their poor surface were rolled down to $1\frac{3}{4} \times 1\frac{3}{4}$ in. billets on a 28-in. mill and illustrations are given of the gradual elimination of the seams and cracks. After further rolling into $\frac{17}{32}$-in. rounds and cold drawing to $\frac{1}{2}$-in. rounds there was only 5% rejection on visual inspection.—A. M. F.

Warehouse Adds Rolling, Annealing Facilities. (*Iron Age*, 1951, **168,** Dec. 6, 164–165). *See* 'Steel Warehouse Installs Cold Reduction Strip Mill,' *J. Iron Steel Inst.*, 1952, 170, Apr., 389.

Tungsten Carbide Rolls for Shaped Wire. (*Wire Ind.*, 1952, **19,** Feb., 132). Particulars are given of rolls with tungsten carbide sleeves, for shaped wire, as manufactured by the Metal Carbides Corp., Ohio.—J. G. W.

The Problem of Transformer Sheets in the Light of New Research. M. Markuszewicz. (*Hutnik* (Katowice), 1952, **19,** 1, 7–15). [In Polish]. The influence of chemical composition, method of steel preparation, temperature conditions during rolling and heat-treatment, and finishing operations on the properties of transformer sheets are discussed.—V. G.

Electrical Sheet Steel. P. Butler. (*Proc. Inst. Elect. Eng.*, 1952, **99**, I, Jan., 30–31). The requirements of electricity supply authorities for low iron losses are given. The losses in the steel and losses which occur with age have been overcome by the use of silicon electrical sheet steel. The original hot-rolling process is being superseded by a cold-rolling process with which a much higher flux density is available.

Ball Bearing Equipped Gauges for Measuring Strip Thickness. (*Ball Bearing J.*, 1951, No. 4, 89–90). An electric measuring apparatus must be used for measuring at high speeds the thickness of strip and wire in rolling mills. The apparatus, described here, is made in Austria, and the gauging rollers are fitted with SKF bearings to specially controlled dimensions to ensure accurate gauging.—T. E. D.

Orb Works, Newport: The Steel Company of Wales Ltd. (Lysaght Division). (*Iron Coal Trades Rev., Special Issue*, 1951, 212–214). This article briefly describes the Orb works, Newport, and the part which it will undertake in the general programme of the Steel Company of Wales, Ltd. The works will continue to specialize in the production of silicon steel sheet and galvanized sheet.—G. F.

The Plant in Action—Rolling Mills and Accessory Plant at Abbey Works. H. H. Ascough. (*Iron Coal Trades Rev., Special Issue*, 1951, 146–157). The author gives detailed descriptions of the design and operation of the 45-in. slabbing mill and 80-in. continuous hot strip mill at the new Abbey works of the Steel Company of Wales, Ltd. The hot-rolled sheet and coil-finishing departments, cold mills, and the continuous pickle line are dealt with.—G. F.

Trostre Plant in Action: Rolling and Processing. J. S. Gazard and G. E. Jones. (*Iron Coal Trades Rev., Special Issue*, 1951, 201–211). The authors give operating details of the new Trostre plant of the Steel Company of Wales, Ltd. Particular reference is made to continuous pickling of the hot-rolled coils, cold reduction in the 5-stand tandem mill, and the electrolytic cleaning, annealing, and electrolytic and hot-dip tinning of the cold-rolled strip.—G. F.

Cold Rolling with Strip Tension: Part II—Comparison of Calculated and Experimental Results. H. Ford and F. Ellis. (*J. Iron Steel Inst.*, 1952, **171**, July, 239–245). [This issue].

Cold Rolling with Strip Tension: Part III—An Approximate Treatment of the Elastic Compression of the Strip in Cold Rolling. D. R. Bland and H. Ford. (*J. Iron Steel Inst.*, 1952, **171**, July, 245–249). [This issue].

Construction: The Cold Reduction Mill Site—Abbey Works. John Laing and Son, Ltd. (*Iron Coal Trades Rev., Special Issue*, 1951, 107–109). A brief description is given of the preparation of the cold reduction mill site and the building of the mill foundations at the new Abbey works of the Steel Company of Wales, Ltd.—G. F.

Trostre Works: The General Plan. H. Leighton Davies. (*Iron Coal Trades Rev., Special Issue*, 1951, 169–171). The author discusses the part in the general programme of the Steel Company of Wales, Ltd., which will be played by the new Trostre cold-reduction plant. The plant will convert hot-rolled coiled steel strip from the Company's new Abbey works into finished tinplates for home and export markets.

Abbey Works—A Description of the Rolling Mills and Accessory Plant. H. H. Ascough. (*Sheet Metal Ind.*, 1952, **29**, Feb., 101–114). Full details are given of the following items at the above works: The 45-in. slabbing mill, slab shears, slab heating, 80-in. continuous mill, hot-strip mill descaling, communications, plate and sheet finishing, coil finishing, cold mills, continuous pickling, cut-up line, and annealing.—P. M. C.

Magnetic Amplifier Regulators for Steel Mill Service. W. R. Harris and L. F. Stringer. (*Blast Furn. Steel Plant*, 1952, **40**, Jan., 77–81). The authors describe a magnetic amplifier voltage regulator for tandem cold-reduction mills developed by the Westinghouse Electric Corp. This amplifier improves performances in many instances and requires little periodic maintenance.—J. P. S.

MACHINERY FOR IRON AND STEEL PLANT

Industrial Locomotives for German Steelworks. (*Railway Gaz.*, 1952, **96**, Mar. 7, 269). A locomotive of the 0–10–0 tank type, which can traverse curves of 460-ft. radius in spite of a 20 ft. 4 in. wheel base, is very briefly described.—T. E. D.

Industrial Gas Turbines with Particular Reference to the Use of Solid Fuel. W. Connell. (*Min. Elect. Mech. Eng.*, 1952, **32**, Feb., 235–245). Gas-turbine design and factors influencing efficiency are surveyed, and various operating cycles are described. Types of alloy used in blades, turbine rotor forgings, and combustion chamber and air-heater parts are given. Industrial applications of gas turbines are reviewed, and the use of solid fuels is considered.—T. E. D.

The Combustion Gas Turbine—A New Tool for the Power Engineer. W. B. Wilson. (*Blast Furn. Steel Plant*, 1952, **40**, Jan., 98–102, 104, 127; Feb., 226–227). The simplicity, space requirements, low installation cost and expected low maintenance and operating costs of combustion gas turbines makes them applicable for electric power generation and for mechanical drive applications such as to drive blowers and compressors in steel mills. There are many different cycle arrangements for the combustion gas turbine. In the open cycle, atmospheric air is used once in its passage through the compressor and turbines, whereas in the closed cycle the same air is used repeatedly and is heated and then cooled from an external source. The types of unit available are discussed. The selection of a turbine for any given application will largely depend upon the ratio of the steam/electric power requirements. Natural gas is an ideal fuel.—J. P. S.

How to Get More out of a Plant Power System with Synchronous Motors. J. C. Moore. (*Blast Furn. Steel Plant*, 1951, **39**, Dec., 1481–1483). The author stresses that high plant power factors are of prime importance when increasing the load on power systems. A unity power factor synchronous motor (current in phase with the voltage) economically improves plant power factor by adding to the kilowatt load on a power system without increasing the reactive kilovoltampères load, since it needs no magnetizing current to operate when normally excited at full load.—J. P. S.

Air Cleaning for Motor Rooms. T. O. Zittel. (*Iron Steel Eng.*, 1952, **29**, Jan., 73–77). The need for a clean atmosphere in motor rooms is stressed, particularly where dusts are conductors of electricity and may produce short-circuits. The functions of motor-room ventilation are laid down. These are to control air temperature, to clean and circulate the air, and to provide make-up air. The air filters are dealt with in particular.—M. D. J. B.

Electrical Equipment for the Metallurgical Industry. (*Metal Ind.*, 1952, **80**, Feb. 1, 89, 90). This is a brief review of the activities of the British Thomson-Houston Co., Ltd., Rugby, during 1951. The major items of equipment which have been supplied include rectifiers, rolling-mill drives, gearing, arc furnaces, and electric motors.—P. M. C.

Light-Sensitive Cells. R. H. Warring. (*Elect. Rev.*, 1951, **149**, Dec. 14, 1198–1200). The theory of the selenium, photovoltaic, and photoelectric cells is given in detail. Recommended uses for each type are discussed and characteristic curves are included. Methods of increasing the emission current by gas-filling and suitable disposition of the electrodes in the cells are described.—H. D. W.

Electronics in the Steel Industry—Past, Present, and Future. H. W. Poole. (*Iron Steel Eng.*, 1952, **29**, Jan., 62–69). After showing how the arduous conditions in steelworks limit the use of electronic equipment in the iron and steel industry, the author considers four fields in which electronics have proved successful, namely: Power electronics, used primarily for power conversion; electronic control; high-frequency electronic heating, and electronic measurements. European practices are described and future trends considered.
M. D. J. B.

Application of Electronic Control. W. R. Harris. (*Iron Steel Eng.*, 1951, **28**, Dec., 89–94). A critical examination is made of the uses of electronic equipment in iron and steel works with special reference to automatic regulating devices. Diagrams are given of four types of regulator with details of rectifiers, photoelectric loop regulators, and regulators for electric flying-shear drives. The capabilities and drawbacks of electronic equipment are considered. There is a great future for this equipment in the iron and steel industry.—M. D. J. B.

Designing Electronic Equipment for Minimum Maintenance. A. P. DiVincenzo. (*Iron Steel Eng.*, 1951, **28**, Dec., 95–99). Design features of electronic equipment are discussed and the selection of components (including resistors, potentiometers, capacitors, transformers, and inductors) mechanical design, and component limitations are considered. The importance of simplicity in the basic circuit scheme and of maintenance are emphasized.—M. D. J. B.

Maintenance of Electronic Control. O. P. Robinson. (*Iron Steel Eng.*, 1951, **28**, Dec., 99–101). Useful hints on the maintenance of electronic apparatus are given. The author stresses that the key to good maintenance of electronic equipment is the skill of the electronic engineer.—M. D. J. B.

Work of the Consulting Engineers: Electrical Installations, Trostre Works. McLellan and Partners. (*Iron Coal Trades Rev., Special Issue*, 1951, 190–200, 214). The above firm acted as consulting engineers for the electrical installations at the new Trostre works of the Steel Company of Wales, Ltd. They describe in some detail the types of electrical plant installed, and the layout of the electrical supply and distribution systems.—G. F.

Bloom and Slab Shear Installed in Austrian Plant. (*Blast Furn. Steel Plant*, 1951, **39**, Dec., 1534). An electrically operated hot bloom and slab shear designed by the Loewy Rolling Mill Division, Hydropress, Inc., New York, has recently been placed in operation by the Alpine Montangesellschaft, Donawitz, Austria. The shear operates in conjunction with a 44-in. blooming and slabbing mill, and is capable of cutting hot blooms up to 16 × 16 × 40 in., exerting a shearing force of 1150 tons.—J. P. S.

A New Slab Shear at Rotary Electric Steel Co. E. T. Peterson. (*Iron Steel Eng.*, 1951, **28**, Dec., 59–64). A new, open side, up-and-down-cut shear developed by a Düsseldorf company and recently installed at the 36-in. blooming mill of the Rotary Electric Steel Co. is described. The shears avoid the difficulties inherent in conventional shearing equipment. They are designed to cut 12 × 12 in. blooms and 40-in. wide by 3½-in. thick slabs and can deal with 17 cwt./min. when cutting small slabs or blooms.—M. D. J. B.

Heavy-Duty Bar-Cropping Machine. (*Engineering*, 1952, **173**, Feb. 8, 182). This article describes a bar-cropping machine manufactured by F. J. Edwards, Ltd., London. It is capable of cutting rounds up to 2 in. in dia. and flats up to 3 × 1 in. and is especially designed for preparing bars used in reinforced concrete.—M. D. J. B.

Selecting Drive Motors for Flying Shears. W. Reid. (*Iron Steel Eng.*, 1952, **29**, Feb., 81–84). The author gives rules for the selection of flying-shear motors for both the non-reversing and reversing types of control, and suggests that the real criterion is adequate accelerating torque. Characteristics are given of a number of motors giving satisfactory service.—M. D. J. B.

Requirements of Sliding Bearings, Particularly those Made of Plastics. H. Mäkelt. (*Z.V.d.I.*, 1952, **94**, Feb. 11, 138–145). The paper reviews the properties of bearing plastics and the requirements they have to fulfil in service. Particulars are also given of lubricants, bearing design, and service performance.—J. G. W.

Conveying Belts. D. R. Woodley. (*Wire Production*, 1952, **1**, Jan. 16–20). The author describes conveyor belts made of woven wire and points out their advantages, *e.g.*, operation in the range − 70 to + 2100° F., and resistance to chemical attack and abrasion. Practical hints on the choice of belt width, and size and type of weave, are given.—J. G. W.

LUBRICANTS AND LUBRICATION

Functions of the Lubricating Engineer. C. R. Hand. (*Iron Steel Eng.*, 1952, **29**, Feb., 85–86). This paper describes the lubricating engineer's problems and how these can be overcome. The results obtained in recent years by works employing full-time lubricating engineers should serve to encourage others. It is claimed that hot bearings and broken gears and shafts are far less frequent today than formerly, which points to good design and lubrication.—M. D. J. B.

Metallic Soap Adds Film Strength to Soluble Oil. N. E. F. Hitchcock and H. M. White. (*Machinist*, 1952, **96**, Jan. 19, 73–77). A soluble oil containing calcium soap has been produced commercially by C. C. Wakefield and Co., Ltd., and marketed under the trade name Solubriol VG. Chromium soap seems to be more efficient than calcium soap for drawing and ironing but less efficient under tube-sinking conditions.

The Stepped Shape Film Applied to a Journal Bearing. F. R. Archibald. (*J. Franklin Inst.*, 1952, **253**, Jan., 21–27). In this mathematical paper it is shown how the stepped film design suggested by Lord Rayleigh (in 1918) might be applied to the problem of lubricating journal bearings.—R. A. R.

Recent Lubricating Problems at Sparrows Point. A. E. Cichelli. (*Iron Steel Eng.*, 1951, **28**, Dec., 110–122). Problems in the lubrication of machinery are discussed and examples from cases at the Bethlehem Steel Co.'s works are cited. These include lubrication of the 160-in. plate mill table line-shaft drive, the use of phenolic and fabric bearings, the lubrication of rod-mill gears, hot strip bearings, hot strip seals, the lubrication of 46-in. blooming mill screws, gas-engine grease systems, and an 18-in. mill drive. The reclamation of bearings and the use of chromium plating to restore original dimensions is described. Lastly the uses of colloidal graphite and babbitt bearings are examined.—M. D. J. B.

Wire Drawing Lubricants. A. E. McAulay. (*Wire Production*, 1952, **1**, Mar., 8–12). The functions of lubricants in wire drawing, and lubricants suitable for various wire-drawing operations are enumerated.—J. G. W.

WELDING AND FLAME-CUTTING

Welded Fabrication Replaces Cast Construction. M. S. Brooke. (*Commonwealth Eng.*, 1952, **39**, Jan. 1, 240–243). Welded fabrication now leads in the field of heavy earth-moving, equipment resulting in a cheaper and stronger product. The application of welding to crawler mounted excavators, rock-crushers, swing-hammer pulverizers, and all-steel road wheels is described. The relief of welding stresses and the inspection and testing of welds are discussed.—J. P. S.

Progress in Welding and Cutting Procedures. Present Position of Welding Technique in the U.S.S.R. (*Schweissen u. Schneiden*, 1952, **4**, Feb., 58–61). A review is given of welding techniques, and difficulties which will be encountered when welding at low air temperatures. (20 references).—U. E.

Progress in the Welding Industry. B. Karnisky. (*Metal Progress*, 1952, **61**, Jan., 59–63). An outline is given of the progress made regarding residual stresses, weldability, structural aluminium, brittle fractures, and high-speed production welding. The author suggests that the steel industry should share the responsibility of the designer by producing and recommending steels for welding which will be satisfactory for the service conditions involved.—J. P. S.

The Reaction of Elements and Their Oxides in the Welding Bath During the Welding of Metals. N. N. Dobrokhotov. (*Avtog. Delo.*, 1948, No. 9, 14–19). [In Russian]. A thermodynamical treatment is given of the reactions taking place in the molten layer during the welding of steels. Gas welding is considered first, equilibrium constants for the systems Fe–O–C and Fe–O–H from the literature being used to calculate the gas compositions neutral with respect to molten iron or to carbon dissolved in iron. The discussion is extended to include the free-energy changes involved in the reactions of slags and alloying elements, and the reactions of silicon and manganese in submerged-arc welding.—S. K.

Predetermination of Preheat and Postheat for Submerged-Arc Welding. C. E. Jackson and A. E. Shrubsall. (*Welding J.*, 1952, **31**, Jan., 1s–10s). Examples are given which illustrate the use of preheat and immediate post-heat for producing welded joints with improved ductility. A number of S.A.E. medium-alloy steels were investigated. It was found that postheat, temperature, and hardness depend on the carbon content and the boron-bearing steels show little effect of boron on the time–temperature for completion of transformation. A number of diagrams show time–temperature relationship for complete isothermal transformation.

Measurement of Calories Generated between Parent Metal and Electrode in Arc Welding. Y. Imai and T. Hagiwara. (*J. Mech. Lab.*, 1951, **5**, Nov., 290–293). [In Japanese].

Heavy Fabrication at Redcar. (*Welding Metal Fab.*, 1952, **20**, Jan., 14–21). A description is given of the welding department at the Redcar works of Dorman Long and Co., Ltd., and their new fabricating shop. Details of plant and some typical large weldments are given.—U. E.

New Frequency Converter Welders Developed for Aircraft Alloys. F. L. Brandt. (*Iron Age*, 1951, **168**, Dec. 27, 72–73). Tentative standards for spot and seam welding machines for use on high-temperature alloys as proposed by the Resistance Welder Manufacturers' Assoc. and the National Electrical Manufacturers' Assoc., are given. Ignitron tube frequency converters operating with low demand and a very high power factor are used.—A. M. F.

High Hardenability Steels Flash-Welded Automatically. J. Ruhlman and B. E. Nye. (*Iron Age*, 1951, **168**, Dec. 20, 95–99). The design practice factors affecting the flash welding of aircraft alloys are given. Preset machines for flash-butt welding of landing gear tubing in various alloys have

been used with only about 2% failures. Weld areas range from 0·025 to 23 sq. in. and as much as 6% welding operation time can be saved. Tack welding and stress relieving have also been eliminated.—A. M. F.

'Build-Up' Welding of Tram Rails. G. Krüger. (*Schweissen u. Schneiden*, 1952, **4**, Feb., 50–55). Investigation on the wear of tram rails which were welded by building-up the surface with weld metal was carried out. A description is given of this welding method being applied to tram rails in Stuttgart using 18/8 austenitic steel electrodes.—U. E.

Developing Electrodes for Welding Austenitic Steels for High-Pressure Vessels. E. Kauhausen and H. A. Vogels. (*Schweissen u. Schneiden*, 1952, **4**, Feb., 35–40). The development of ferrite-free austenitic electrodes for welding high-pressure vessels and thick-walled tubes is described.—R. A. R.

MEZ-04 Type Electrodes for Welding Low-Carbon Steels. N. N. Kriukovskii. (*Avtog. Delo*, 1949, No. 3, 9–11). [In Russian]. The effects of the arc-welding process and the influence of electrode coatings on the properties of welds in low-carbon steels are briefly considered. An electrode coating is described which gives slags suitable for welding in any position either by the ordinary or the deep-penetration method.

Investigation of Some Types of Electrodes for the Arc-Welding of EYal-T Type Steel. E. M. Lapitskaya and I. N. Gerasimenko. (*Avtog. Delo*, 1948, No. 9, 12–14). [In Russian]. The development of intercrystalline corrosion in welded seams deposited on a high-alloy steel used in high-temperature chemical plant is considered, and an investigation on this effect is described. Specimens 10 and 5 mm. thick were welded with stabilized and unstabilized steel electrodes and subjected to bend and tensile tests and structural investigation after corrosion tests, carried out by immersing degreased specimens in boiling acidified copper sulphate for 72 hr. Stabilization of the deposited metal by niobium produced seams showing no tendency to intercrystalline corrosion even after heating at 650° C. followed by slow cooling. Molybdenum was only effective in the absence of this heat-treatment, while titanium had no effect.—S. K.

MACHINING AND MACHINABILITY

Machinability. (*Automobile Eng.*, 1952, **17**, Jan., 27–31). This article is a résumé of some recent American work on the machinability of cast irons. Microstructures of cast iron are briefly described, and the relative hardnesses of the normal constituents are discussed. The results of face milling, lathe turning, and multi-spindle drilling operations on flake graphite and nodular graphite irons are quoted.—P. M. C.

Shape of Chip in Grinding. A. Hornung. (*Acta Technica Academiae Scientiarum Hungaricae*). 1951, **1**, 3, 241–259). [In German].

Surface Faults in Precision Grinding. L. Nava. (*Riv. Mecc.* 1951, **2**, Sept. 29, 11–14). [In Italian]. The author gives a detailed description of grinding cracks and burns in steels and shows how these can be detected. Methods of detection are described and suggestions are put forward for the prevention of injury to ground surfaces.—M. D. J. B.

Eliminate Grinding Damage—Reduce Tool Failure. H. Pottle. (*Steel*, 1951, **129**, Dec. 31, 56–57). The damage caused to tool steel by the heat generated in grinding can cause cracking or surface hardening. This can be alleviated by passing coolant through the grinding wheel, if it is of the porous vitreous bonded type, where it is atomized by centrifugal force and is applied at the point of contact.—A. M. F.

How Workpiece Structure Affects Tool Life. M. C. Shaw and P. A. Smith. (*Machinist*, 1951, **95**, Dec. 22, 1942–1945). Matrix hardness, alloying constituents, inclusions, and the tendency of the work material to create a built-up edge, all influence the kind and degree of tool wear. The behaviour of carbon steels, alloy steels, austenitic materials, and cast irons in machining operations is explained.—E. C. S.

Machining Steel Moulds for Rubber Tyres. A. Felton. (*Machinery*, 1952, **80**, Jan. 3, 13–17). The article deals with the manufacture of cast steel moulds for curing and vulcanizing rubber tyres at the B. F. Goodrich plant at Akron, U.S.A.

Honed Edges Cure Carbide Ailments. C. Frank. (*Steel*, 1951, **129**, Dec. 17, 106). If carbide tools are honed using a 320-grit silicon carbide stone and all cutting edges chamfered 0·002–0·005 in. to 45° angles, there will be a decided increase in their efficiency and strength of the cutting edge without ill effects on normal cutting action. Unhoned carbide tools tend to crumble at the cutting edge due to irregularity in grinding.—A. M. F.

Nerve and Sharp Tools Machine Any Stainless at High Speeds. E. von Hambach. (*Machinist*, 1952, **96**, Feb. 23, 271–274). Machining speeds may be greatly increased by proper grinding and fine surface finish on cutting edges of tools, applying coolant in the right place, and using rigid robust machine tools with ample power.—E. C. S.

Cutting Speed May Double or Triple When Science Guides Machining. E. J. Tangerman. (*Machinist*, 1952, **96**, Jan. 5, 18–21). Fluids, temperatures, machinability, and microstructure are all important in machining problems. A recent bibliography on machinability and high-speed machining is included.—E. C. S.

Oil Jet Increases Cutting Tool Life. (*Iron Steel Eng.*, 1952, **29**, Jan., 146–148). This article describes two developments in cutting technique which are claimed to increase cutting-tool life by up to 1200%. These improvements by the Gulf Research and Development Co., concern cutting-fluid application. A small high-speed jet of oil is directed from below the tool and passes through the space between the work and the side relief face of the tool. The tool is efficiently lubricated and heat is transferred away from the cutting edge, giving increased tool life, better surface finish, and faster speeds.—M. D. J. B.

Choose Your Metal-Cutting Fluids with Care. L. Salz. (*Machinist*, 1951, **95**, Dec. 29, 1987–1990). The article explains what cutting fluids are, and what their function is. Since cutting fluids represent a minor cost in metal fabrication, it is false economy to buy them on the basis of price alone. A good coolant may increase tool life, reduce rejects, allow higher speeds and feeds, and reduce stoppages.—E. C. S.

PROPERTIES AND TESTS

Testing Today and Tomorrow. F. G. Tatnall. (*Metal Progress*, 1952, **61**, Jan., 64–67). The author outlines progress in the application of electronics in testing equipment and attempts to forecast how much devices might meet future needs in creep, rupture, and fatigue testing.—J. P. S.

Methods and Laboratory Equipment for the Study of Metals. M. Ferrero. (*Riv. Mecc.*, 1951, **2**, May 25, 5–11; June 10, 5–10; June 23, 17–20; July 7, 11–16; July 21, 11–15; Aug. 4, 9–13; Sept. 15, 5–14; Sept. 29, 5–9; Nov. 11, 5–10; Dec. 22, 5–12). [In Italian]. A comprehensive review is given of methods and equipment used in modern metallurgical laboratories. Detailed consideration is given to all types of mechanical test, examination of failures, Vickers, Rockwell, Brinell, and Shore hardness tests as well as resilience, flexural, torsional, tension, impact, and fatigue tests. Practical methods of testing are discussed. Laboratory testing of metals at high temperatures is dealt with next, four methods being described: the rapid fractive test, and the creep, hardness, and fatigue tests. Lastly, the author reviews spectrographic and X-ray methods.

Mechanical Testing. F. A. Roper. (*New Zealand Eng.*, 1951, **6**, Nov. 16, 442–444). This is a brief article, describing in an elementary manner the tensile and fatigue tests. The Johansson extensometer is described, and the elastic property of steel and the use of Young's modulus are discussed.—P. M. C.

On the Relations between Structures and Mechanical Properties of the Bicycle Chain's Outer Links. K. Futaki. (*J. Mech. Lab.*, 1951, **5**, Aug., 135–139). [In Japanese]. The author finds that the slope of the stress/strain curve of quenched and tempered links is influenced by the growth of granular cementite.—J. G. W.

On the State of Stress in a Plastic-Rigid Body at the Yield Point. R. Hill. (*Phil. Mag.*, 1951, **42**, Aug., 868–875). The yield point of a plastic rigid body is defined as the moment when deformation first becomes possible as the load is increased. The practical significance of the yield-point load for an actual plastic-elastic body is discussed. It is then shown that part of the plastic zone, at the yield point, namely, the part where deformation occurs, depends only on the current surface tractions and not on the previous loading programme. By the principle of maximum plastic work and its complementary minimum principle (Hill, 1950) approximations from above and below to the yield-point load can be obtained; some examples are given.—J. P. S.

The Flow of Metals. E. N. da C. Andrade. (*6th Hatfield Memorial Lecture: J. Iron Steel Inst.*, 1952, **171**, July, 217–228). [This issue].

Theory of Plasticity I—Correlation between Lattice Transformation and Plastic Gliding of Metals. S. Takeuchi and H. Suzuki. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Feb., 50–59). [In English]. Two fundamental relations for expressing the resistance to slip in terms of the thermodynamic function were derived from the dislocation structure.

Theory of Plasticity II—Critical Shear Stress of Binary Alloys. S. Takeuchi and H. Suzuki. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Feb., 60–67). [In English]. The critical shear stress was calculated. The results are in good agreement with observed values for alloys in which the atoms of the constituents are of nearly the same radius.—J. G. W.

Contribution to the Problem of Error Compensation in the Measurement of Residual Stresses in Hollow Cylinders and Tubes. H. Bühler and W. Schreiber. (*Metall*, 1952, **6**, Feb., 77–80). The authors present a refinement of their recently proposed method of stress computation based on Sachs, boring procedure. The method is illustrated by a full computation for a heat-treated steel hollow cylinder.—J. G. W.

A Theoretical Investigation of the Compression of a Ductile Material between Smooth Flat Dies. A. P. Green. (*Phil. Mag.*, 1951, **42**, Aug., 900–918). A theory is suggested to describe the distribution of stress and velocity in a block of ductile material symmetrically indented on opposite sides by two smooth flat dies. The theory is two-dimensional and an ideal plastic-rigid material is assumed. Slip-line fields are proposed for all ratios of width of dies to height of block greater than unity. It is found that the velocity field transforms into its corresponding slip-line field. Since the velocities are known along only one slip-line boundary, the usual numerical procedure for calculating the field has to be modified and influence coefficients are introduced. Solutions are computed for width/height ratios between one and two; simple analytical relations hold between these ratios and the corresponding velocity discontinuities in the field. The deformation after different finite indentations is illustrated by photographs of experiments using plasticene models and aluminium alloy strip. Similar fields are proposed for extrusion or drawing through a wedge-shaped-die.—J. P. S.

Some Experimental Indications of the Stresses Produced in a Body by an Exploding Charge. J. S. Rinehart. (*J. Appl. Phys.*, 1951, **22**, Sept., 1178). By examining the inelastic deformations produced in a block of steel by the detonation of an explosive charge on its surface it has been possible to establish qualitatively certain features of the stress distribution. Generally, the stress pattern appears to correspond closely to that which would be produced by a static load except that shock-twinning and fracturing both occur in the dynamic case because of the high rates of strain involved.—J. P. S.

Internal Stress Due to Quenching in Cylindrical Steel Ingots. T. Hirone and N. Tsuya. (*Sci. Rep. Res. Inst. Tôhoku. Univ.*, A, 1949, **1**, Oct., 169–173). [In English]. The relations between residual internal stresses due to quenching and quenching temperature for large cylindrical ingots are obtained from the elasticity theory.—J. G. W.

New Possibilities for the Radiographic Determination of Stresses with Rays of Short Wavelength. H. Möller. (*Métaux-Corrosion-Indust.*, 1951, **26**, Nov., 460–469). The advantages of using molybdenum radiation instead of the more normal cobalt radiation for Debye-Scherrer X-ray diffraction work on steels are examined. The characteristic diffuse photographs normally obtained from samples of steels irradiated by molybdenum radiation can be markedly improved with a 0·2-mm. aluminium filter; the exposure time is not unduly prolonged. Similar clear photos may be obtained from steels stretched as much as 46%. The design and use of a back-reflection camera for the examination of surfaces in which the primary X-ray beam is directed on to the surface at an oblique angle are described.—B. G. B.

New Non-Destructive Electronic Methods for Testing Materials. F. Förster. (*Métaux-Corrosion-Indust.*, 1951, **26**, Dec., 497–513). A mathematical investigation into the theory of the methods is first given. Instruments using variations in magnetic properties or electrical conductivity for the detection of structural defects are described. The use of the cathode-ray oscillograph to give a visual indication of structural defects is explained. Devices for the automatic testing of articles, not only for cracks, but also for the efficiency of hardening are also described.—B. G. B.

Structural Analysis of Fractures. H. de Leiris. (*Métaux-Corrosion-Indust.*, 1951, **26**, Dec., 471–496). A large number of photographs of fractures are examined. Fractures are classified in two groups called progressive and brittle fracture, respectively. These are discussed in detail and the effect of factors such as a direction of load, corrosion, and grain structure are illustrated. The examination of fractures to discover the cause of disruption of a spherical gas reservoir and cracking into two parts of an oil tanker are described.

Review of the Fatigue of Materials Field. R. E. Peterson. (*Appl. Mech. Rev.*, 1952, **5**, Jan., 1–2). Papers on the following aspects of the fatigue of metals are briefly reviewed: Statistical aspects; the behaviour of metals and structures under vibration at different amplitudes, geometrical variations causing stress concentrations; combined stresses; processing effects; fatigue at elevated temperatures; and fundamentals of fatigue.—J. P. S.

Fatigue of Steels. (Motor Industries Research Assoc.: *Automobile Eng.*, 1952, **17**, Jan., 35–40). The article is based on the first part of the M.I.R.A. report, "The Fatigue Strength of Steels," by R. J. Love. Topics discussed are: Stress/stress-cycles diagrams and their application to design; the influence of mean stress on limiting stress; criteria of failure under combined stresses; under- and over-stressing and impact; and chafing and corrosion fatigue. (28 references).

The Fatigue of Metals. Notched Specimens. Results of LFEM Tests (1948–1950). M. Ros. (*Rev. Mét.*, 1951, **48**, Oct., 723–733). Experiments carried out between 1925 and 1950 on light alloys and steels show that the Coulomb–Mohr theory is sufficiently exact to be considered as a general theory of the rupture of metals for both static and fatigue failure at normal and high temperatures under simple or multiaxial stress and for specimens with or without notches.—A. G.

On the Correlation Between Stress Gradient and Elastic or Fatigue Failure. H. Nakazawa. (*Mem. Fac. Techn. Tokyo Metropolitan Univ.*, 1951, No. 1, 1–10). [In English]. The author proposes a hypothesis for the mechanism of elastic or fatigue failure in the presence of a stress gradient, whereby yield points and fatigue limits are calculated.—J. G. W.

Torsional Fatigue Machine with Torque Control. R. J. A. Paul and J. R. Bristow. (*Engineering*, 1952, **173**, Jan. 4, 25–28). The authors describe a torsional fatigue machine having controlled torque, developed mainly for work on cast crankshafts. In this machine, the maximum torque, in a completely reversed torque cycle, is electronically controlled to $\pm$ 2%. The machine produces total failure of the specimen, since the torque does not decrease with the starting of a crack, and consequently gives less scattered results than a machine of the constant-strain type. The machine consists essentially of a freely suspended system comprising two inertia discs connected through extension shafts to each end of a crankshaft or other specimen. The system can be excited in a simple one-node, free-ended oscillation by a rotating out-of-balance weight.—M. D. J. B.

Shot Peening Deserves Consideration During Initial Design. E. H. Abbe, T. Backus, and J. C. Straub. (*S.A.E. J.*, 1952, Jan., 41, 46). This very brief article is based on three papers given separately by the authors at a meeting of the S.A.E. Iron and Steel Technical Committee. The use of shot-peening for improving fatigue strength, thereby allowing changes in design of certain components, is the main theme.—P. M. C.

On the Internal Stress and the Internal Friction of Metals. I—On the Mechanism of Fatigue. H. Sato. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1**, Oct., 203–206). [In English]. In order to elucidate the mechanism of fatigue, specimens of normalized 0·2% carbon steel were subjected to bending fatigue and their internal friction was measured. Evidence of convergence of the internal stresses to a limiting value coinciding with the endurance limit was thus obtained; this was followed by a sudden increase in internal friction, presumably caused by the appearance of the crack which leads ultimately to failure. Subject to certain reservations, these results afford support to Orowan's theory of fatigue.—J. G. W.

Damping Capacity under Very Low Stresses. M. R. Cabarat. (*Mém. Soc. Ing. Civils France*, 1951, **104**, May–June, 167–183). Previous work is surveyed. A new method of determining damping capacity under weak stresses in which the vibrations of a resonator are maintained by electrostatic action is described. The influence of the type of graphite formation on the damping capacity of iron was studied by this method.

The Damping Capacity of Materials and Its Determination with an Amsler Electromagnetic Pulsator. M. A. Tenot. (*Mém. Soc. Ing. Civils France*, 1951, May–June, 184–191).

The theory and details of the method of measuring damping due to Amsler are described. The results of experiments on iron, plastics, and open-hearth furnace steel are given.

Clarification of the Term 'Hardenability' of Steel. E. Bickel. (*Schweiz. Arch. Wiss. Techn.*, **17,** Nov., 347–348). The use of the German '*Härtbarkeit*' for 'hardenability' is deprecated on the grounds of its ambiguity, and the terms *Durchhärtbarkeit* and *Maximalhärtbarkeit* are proposed for distinguishing between 'hardenability' (as measured by Jominy or Grossmann tests) and 'intensity of hardening' (the maximum hardness attainable), respectively.—H. R. M.

Simple Tester for Hardness of Hot Materials. R. F. Domagala and W. R. Johnson. (*Metal Progress*, 1951, **60,** Dec., 72–73). A rapid reproducible method for testing hot hardness of materials at temperatures approaching their melting points has been developed at the Armour Research Foundation of Illinois Institute of Technology. An induction-heated molybdenum anvil heats the specimen by contact. The indenter is a natural octahedral diamond crystal.—J. P. S.

Rapid Method for Determining the Hardness of Weld Seams. O. G. Vegner. (*Avtog. Delo*, 1949, No. 3, 21). [In Russian]. A new technique for the hardness testing of weld seams in positions so inaccessible that microscopic measurement of the size of the indentation is impossible, is proposed. An image of the indentation is obtained on a disc of lacquered pressboard by placing the disc in a special holder over the indentation and striking gently. The disc is then removed and examined under the microscope.—S. K.

Internal Friction in Iron and Steel. J. D. Fast and L. J. Dijkstra. (*Philips Tech. Rev.*, 1951, **13,** Dec., 172–179). The internal friction of torsional oscillations of small amplitude of iron and steel wires is an after-effect phenomenon, which under certain conditions arises from the diffusion of foreign atoms in the iron lattice. The phenomenon is used to study the precipitation of carbon and nitrogen, which is responsible for quench ageing. Damping experiments are described which show that manganese has no influence upon the precipitation of carbon, but that it retards the precipitation of nitrogen.—P. M. C.

Ageing Phenomena in Iron and Steel after Rapid Cooling. J. D. Fast. (*Philips Tech. Rev.*, 1951, **13,** Dec., 165–171). The effects of manganese, carbon, and nitrogen on the quench ageing of iron and steel have been studied. The last two constituents cause considerable ageing, which is ascribed to precipitation as carbides and nitrides from the supersaturated solution in α-iron, caused by rapid cooling. Manganese appears to be capable of supressing the ageing of iron containing nitrogen, but not that of iron containing carbon. (13 references).—P. M. C.

The Thermodynamic Interpretation of Some Phenomena in the Ageing of Alloys. L. S. Palatnik. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **81,** 1, 39–42). [In Russian].

The Rapid Softening of Cold-Drawn Austenitic Stainless Steels. F. A. Hodierne and C. E. Homer. (*J. Iron Steel Inst.*, 1952, **171,** July, 249–253). [This issue].

Observations on the Wear Problem. W. Späth. (*Schweiz. Arch. Wiss. Techn.*, 1951, **17,** July, 214–219). The nature of the problem of wear and its relation to hardness and structure of the material are discussed. Particular reference is made to the relation between wear and the fatigue failure produced by rolling contact under load.—H. R. M.

The Use of Radon and Radioactive Isotopes for the Non-Destructive Testing of Materials F. Gottfeld. (*Métaux-Corrosion-Indust.*, 1951, **26,** Nov., 456–459). A review is made of the advantages of using the new radioactive isotopes now readily available from atomic piles.—B. G. B.

Geiger-Müller Counters and Their Technical Applications. R. Berthold and A. Trost. (*Métaux-Corrosion-Indust.*, 1951, **26,** Nov., 442–455). A short account is given of the principle of the Geiger-Müller tube and the necessary ancillary counters. Their use for the location of internal defects in metals, the examination of inaccessible surfaces for corrosion, and measuring the thickness of sheet-metal products is explained. Applications to analytical problems are discussed. A traversing Geiger-Müller tube is described for measuring the intensity of the X-ray reflections obtained by the Debye-Scherrer technique.—B. G. B.

Cobalt 60 in the Foundry. J. C. Pennock. (*Amer. Foundryman*, 1952, **21,** Jan., 60–61). A simple introduction is given to the use of this isotope for the examination of castings by radiography.—E. J. D. S.

The Application of X-Rays to the Study of the Mechanism of the Plasticity of Metals. A. Guinier. (*Métaux-Corrosion-Indust.*, 1951, **26,** Nov., 427–432). The use and interpretation of Laue and Debye-Scherrer X-ray methods for the study of deformed structures are explained. The application of microradiographs for locating structural defects is also discussed. Certain modifications, orientational variations, and dispersion of crystallites are very easy to reveal and to follow quantitatively by X-rays.—B. G. B.

Xeroradiography Can Cut X-Ray Inspection Costs. M. D. Phillips and S. A. Wenk. (*Iron Age*, 1951, **168,** Nov. 29, 86–89). A new type of X-ray plate is described. This consists of an electrically conductive backing material, such as a metal sheet or coated glass, the face of which is coated with a smooth layer of a suitable semi-insulator sensitive to X-rays. This coating, selenium or sulphur, a non-conductor, becomes conductive when exposed to X-rays. The image may be developed immediately by a dry process and can be readily transferred to ordinary paper. Speeds are high and the plates can be used hundreds of times.—A. M. F.

Determination of the Coefficient of Thermal Conductivity of Metals. E. Rousseau. (*Chim. et Ind.*, 1952, **67,** Feb., 242–248). A detailed description of an apparatus for the accurate determination of thermal conductivity is given. The material under test is heated at one end and cooled by water at the other. The difference in temperature between two points a known distance apart, when a known amount of heat is removed, allows the calculation of the coefficient.—T. E. D.

On the Abnormality in the Thermal Expansion of Iron–Platinum Alloys. H. Masumoto and T. Kobayashi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2,** Dec., 856–860). [In English]. Based on a rule concerning Invar, previously proposed by Masumoto, the thermal expansion of iron–platinum alloys was investigated. The smallest coefficient of linear expansion is $-12{\cdot}5 \times 10^{-6}$ for the 53% Pt alloy in the 0–40° C. range.—J. G. W.

The Electrical Conductivity of Magnetite. H. Watanabe and N. Tsuya. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A., 1950, **2,** Feb., 29–35). [In English]. The electrical conductivity of magnetite was measured in the temperature range which includes the transformation temperature. Single-crystal measurements revealed a marked jump in conductivity at the transformation temperature.—J. G. W.

Applications of the Triboelectric and the Thermoelectric Effects to the Sorting of Metals. A. Doscheck. (*Non-Destructive Test.*, 1951, **10,** Autumn, 22–28). Two newly developed metal sorting instruments, the 'Tribosorter' and the 'Thermosorter,' are described and illustrated. The former has a sorting head containing two contact rods which are reciprocated across the test sample, the triboelectric output due to friction being used to indicate the type of metal. The 'Thermosorter' has a sorting head which heats the test sample and uses it as one component in a thermocouple. The e.m.f. generated is again used to indicate the type of material under test.—P. M. C.

Heat-Resisting Cast Steel. H. Lüling. (*Schweiz. Arch. Wiss. Techn.*, 1952, **18,** Jan., 22–32). This paper discusses how the strength of steel castings at high temperatures is influenced by macrostructure and microstructure, chemical composition, heat-treatment, grain size, and the shape of the casting. Large gas-turbine components are now successfully cast and a few of these are illustrated.—H. R. M.

Radiographic Microstructural Research on the Creep of Steel. W. Epprecht. (*Schweiz. Arch. Wiss. Techn.*, 1952 **18,** Jan., 10–21). The creep process in 18/8 steel, a special austenitic steel, and a Ni–Cr alloy of face-centred cubic structure was investigated over the range 570–750° C. by means of X-ray diffraction patterns. In these materials creep was found to be primarily a process of slip in the austenite crystals. Creep results in strain-hardening of these crystals, but, on the other hand, it can also destroy the existing hardening effects. High loads result in marked strain-hardening, while low loads applied for a long time favour the softening process, so that an equilibrium between the two opposing processes is attained.

Some Problems of Heat-Resistant Steels from the User's Point of View. W. Stauffer. (*Schweiz. Arch. Wiss. Techn.*, 1951, **17,** Dec., 353–364). Work undertaken in the Escher Wyss laboratories to solve problems arising in the application of heat-resistant steels to high-temperature steam- and gas-turbine construction is described. These problems include scatter of creep-test results, creep strength and mechanical

properties of weld metal, resistance of tubes to internal pressure, creep strength of castings, the effect of combustion gases and the constituents of the ash on heat-resistant steels, and non-destructive testing of castings.—H. B. M.

Universal Machine for Micro-Mechanical Testing at Various Temperatures. S. F. Iur'ev. S. E. Rechitskaya, and A. N. Mishurinskii. (*Zavodskaya Laboratoriya*, 1950, No. 1, 70–77). [In Russian]. A description is given of a simple and reliable testing apparatus for carrying out mechanical tests on specimens up to 2 mm. in dia. and 25 mm. long. The load is applied by a motor with the aid of reduction gears and a system consisting of a pivoted bar and a cantilever bar. The movement of the two bars between which the specimen is fixed is magnified with the aid of an optical-mechanical system and photographically recorded. The calibration of the mechanical and optical scales is described, and the errors in determining relative elongation and stress are said to be 1·3% and 0·9 kg./sq. mm., respectively. For bend testing, a special attachment is fixed to the bars of the machine, and for tensile tests at high temperatures the specimen is located in a small furnace whose rigid casing forms part of the mechanical system. Extension diagrams, recorded for hardened and untempered specimens of a high-strength low-carbon chromium–nickel–molybdenum steel, are shown ; these enable the mechanical properties to be determined with an accuracy sufficient for practical purposes. Similar diagrams for specimens of the same steel subjected to cementation show that the case-hardened layer had a very low plasticity. Curves for nitrided specimens were obtained at 20°, 300°, 450°, 500°, 550°, and 600° C., and these are used to explain the deformation of nitrided parts above 500–520° C. in terms of the interaction of the core and the nitrided layer. These curves are compared with the corresponding curves obtained with specimens of normal size and show satisfactory agreement.—S. K.

Effect of Cold Drawing on Creep-Resisting Molybdenum Steel Steam Pipe. E. A. Jenkinson and D. C. Herbert. (National Physical Laboratory : *Engineering*, 1952, **173,** Mar. 14, 345–347). The authors examine how cold drawing affects the creep resistance of molybdenum steel steam pipes, and also examines the effects of cold working on the graphitization of steels after welding. Tests are described and the results discussed. They conclude that the cold drawing of the two steels examined improved the surface finish, and did not lower their creep resistance, provided the pipes were normalized after cold drawing. Moreover, no tendency to graphitize was observed.—M. D. J. B.

Creep and Stress-to-Rupture Properties of Pressure-Vessel Steels. R. D. Wylie and H. Thielsch. (*Welding J.*, 1952, **31,** Jan., 11s–19s). Creep and stress-to-rupture data are reviewed to provide the latest knowledge on the characteristics of pressure-vessel materials. The manner in which microstructure and heat-treatment affect creep strength is discussed.—U. E.

Production and Properties of Discs for Aircraft Gas-Turbine Engines. H. W. Kirkby. (*Metal Treatment and Drop Forg.*, 1952, **19,** Jan., 3–11). Creep resistance at elevated temperatures is one of the most important properties required of steels used for aircraft gas turbines. The properties of Mo–V and Cr–Mo–V steels are discussed, and the author then outlines the development and properties of R.ex 448 and R.ex 467. The former, which is ferritic, contains 10–13% Cr and 0·30–0·60% Nb ; the latter is austenitic and has a complex composition which includes 9·5% Ni, 14·5% Cr, and a little molybdenum and copper. (11 references).—P. M. C.

Phenomenological Theories of Creep. A. Graham. (*Engineer*, 1952, **193,** Feb. 8, 198–201 ; Feb. 15, 234–236). A formula with four adjustable constants relating permanent strain to stress, time, and temperature, is shown to represent successfully the decelerating stage of uniaxial creep in several dissimilar metals. It embraces many well-known empirical laws of creep, for non-metals as well as metals, and it may be generalized to cover certain anomalies. Its applications to tertiary creep, the tensile test, and stress relaxation are considered, together with its limitations as an equation of state.

A New Contribution to the Study of the Effect of the Microstructure on the Heat Resistance of Steel. G. Delbart and M. Ravery. (*Rev. Mét.*, 1952, **49,** Jan., 67–88). The effects of microstructure, temperature, and load on the creep resistance of a chromium–molybdenum steel (0·12% C) have been studied by 35-hr. and 1000-hr. tests. The favourable effect of a preliminary heating to 450° or 575° C. is demonstrated and the results are confirmed for steels with 0·31% and 0·53% carbon.—A. G.

Influence of Microstructure on Creep Resistance. G. Delbart and M. Ravery. (*Metal Progress*, 1951, **60,** Dec., 62–68). Chromium–molybdenum steel (0·12% C; 0·02% P; 0·01% S; 0·16% Si ; 0·7% Mn ; 0·6% Cr ; 0·65% Mo ; 0·03% Al ; and <0·01% Ti) was tested. This steel, after the usual hot-work, was heat-treated in nine different ways to as many different microstructures. Creep tests were made on the test pieces so heated. The tests demonstrated the strong influence of microstructure on the service performance of low-alloy, high-temperature steels.—J. P. S.

Rôle of Thermal, Mechanical and Surface Treatments on the Charging of Iron with Cathodic Hydrogen. J. Duflot. (*Rev. Mét.*, 1952, **49,** Jan., 35–50). Tests on an extra-mild Armco iron show that : (*a*) Electrolytic polishing permits the greatest hydrogen absorption ; abrasion makes the surface almost impermeable ; and (*b*) thermal and mechanical treatment affect hydrogen content by modification of the structure and of the state of impurities present.—A. G.

An Experimental Investigation of the Diffusion of Electrolytic Hydrogen through Metals. H. R. Heath. (*Brit. J. Appl. Phys.*, 1952, **3,** Jan., 13–18). Experiments have been made to test whether hydrogen produced electrolytically on one side of a plate will diffuse through it. The metals examined were iron, nickel, cobalt, copper, zinc, silver, palladium, platinum, and lead. Diffusion was observed only for iron and palladium. Measurements were made with iron showing how the amount of diffused gas varied with time and how the rate of steady diffusion varied with the thickness of the plate. The variation in the rate of diffusion with the electrolysing current density was observed for plates of iron and palladium. The results showed that a threshold value of current density does not exist and that for low values of current density the rate of diffusion is approximately proportional to it. The diffused gas appears to be in the ordinary molecular state. A simple theory explaining the general character of the experimental results is given.—J. P. S.

Absorption of Nitrogen by Molten Iron Alloys. I—Study on Pure Iron. T. Saitô. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Dec., 411–417). Results of experiments on the absorption of nitrogen by molten iron in the range 1530–1750° C. were in fair agreement with an analysis based on statistical thermodynamics with the assumption that the structure of molten iron is quasi-crystalline and absorbed gas atoms are situated interstitially in vacant spaces of the iron lattice.—J. G. W.

Nitrogen as the Alloying Element in Steel. I—On the Effect of Nitrogen on the Temper Brittleness in Steels. Y. Imai and T. Ishizaki. (*Sci. Rep. Res. Inst. Tôhoku Univ.* A, 1950, **2,** Dec., 890–908). [In English]. The investigation is concerned with the effect of nitrogen on the temper brittleness of carbon and low-manganese steels. Temper brittleness appears in medium-carbon steels with additions of 0·010% N and becomes more conspicuous with increasing nitrogen owing to the change in solubility at temperatures below about 580° C. Temper brittleness may be prevented by the addition of elements with great affinity for nitrogen ; both aluminium and titanium are effective ; molybdenum and tungsten are not necessary, whilst carbon has little effect.—J. G. W.

Absorption of Nitrogen by Molten Iron Alloys. II—Study on Fe–Ni, Fe–Cr, and Fe–Mn Alloys. T. Saitô. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Dec., 419–424). [In English]. Satisfactory agreement between theory and experiment was obtained. The principal conclusion is that in the alloys the atoms of the metal with greater affinity for nitrogen congregate round the absorbed nitrogen atoms.

Absorption of Nitrogen by Molten Iron Alloys. III—Study on Fe–C and Fe–Si Alloys. T. Saitô. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2,** Dec., 909–916). [In English]. In Fe–C alloys the saturation value of nitrogen decreases with increasing carbon content. In Fe–Si the saturation value increases at first with up to 0·5% of silicon ; it then decreases up to 14% whereafter it resumes its upward course. It is therefore concluded that the quasi-crystalline lattice of molten Fe–C and Fe–Si alloys differs from that of Fe–Ni, Fe–Cr, and Fe–Mn formerly reported, *i.e.*, it is ordered. Particulars are also given of the rates of absorption of nitrogen by iron alloyed with nickel, carbon, silicon, manganese, and chromium.—J. G. W.

The Diffusion of Elements in Molten Iron. B. V. Stark,

E. V. Chilishchev, and E. A. Kazachkov. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, No. 11, 1689–1695). [In Russian]. An experimental determination of the diffusion coefficients of manganese and silicon in molten iron is described. Experiments were made in the temperature range 1680–1806° C.—V. G.

An Experimental Verification of Electrochemical Theory in Respect of Systems of Molten Iron–Carbon–Silicon Alloys. O. F. Esin, and L. K. Gavrilov. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, No. 8, 1234–1242). [In Russian]. Experimental determination of electromotive forces in systems composed of molten alloys of iron, carbon, and silicon, and of slags containing oxides of calcium, magnesium, and silicon at between 1470 and 1480° C. are described. The silicon content was varied from 0·65% to 43%. The alloys were saturated with respect to carbon. Conclusions are drawn regarding the validity of electrochemical theory for the systems.—V. G.

An Investigation on Boron-Treated Steels. I—On the Hardenability of Boron-Treated Medium-Carbon Steels, Especially the Effect of Nitrogen Content in Steels. Y. Imai and H. Imai. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2,** Apr., 260–269). [In English]. It was found that maximum hardenability is obtained with an addition of 0·003% boron ; hardenability decreased sharply with further additions. Nitrogen in excess of 0·008% markedly decreases the effect of boron until, with 0·02% nitrogen, boron has no effect. The effect of boron is most pronounced in thoroughly deoxidized and denitrogenized steels.—J. G. W.

Metallurgy at the Bureau of Standards in the Past 50 Years. J. G. Thompson. (*Metal Progress*, 1951, **60,** Dec., 51–57). The history of the work done on metals by the National Bureau of Standards since its establishment in 1901 is outlined. The present organization of the Bureau is described.—J. P. S.

Material Specifications and Standardization. A. A. Hofman. (Australian Inst. Metals and Inst. Production Engs. : *Australasian Eng.*, 1951, Dec. 7, 105–121). This is a general treatment of the subject, in which the nature of a specification and its uses and limitations are discussed. Suggestions are offered to those responsible for the drawing up of specifications, and the preparation and use of standards are described.—P. M. C.

Steel Specifications. N. E. Woldman. (*Iron Age*, 1952, **169,** Jan. 3, 260–326, 350–380, 518–520). A brief analysis is given of various civilian, federal, and military specifications listing the composition and form of the material referred to and noting whether or not it is similar to a better-known standard specification.—A. M. F.

SAE Steel Committee Leads Alloy Conservation Program. (*Iron Age*, 1951, **168,** Dec. 27, 74–76). Fourteen new grades of A.I.S.I.–S.A.E. steels, calculated to replace highly alloyed grades, are listed. Five boron steels have been accepted as H-band grades ; their hardenability curves are given.—A. M. F.

Standard Steels and Their Place in the Defence Effort. W. M. Kelley. (*Amer. Iron Steel Inst.*, 1951, Preprint).

Cast Alloy Reference Sheet, No. 5. (*Chem. Eng. Prog.*, 1951, **47,** Nov., 592). The metallurgical properties and corrosion resistance of low-carbon, 18% Cr, 8% Ni, 3% Mo alloy steel are listed in detail.—T. E. D.

Three-Layer Steel and Plough Mould Boards. M. Dubois. (*Mét. Constr. Mécan.*, 1951, **83,** Nov., 879–880). The damaging effects of soil adherence to plough mould boards are stated. Two methods of overcoming this are modified design and use of hard and polished metal surfaces. Two materials normally used are : (1) Open-hearth steel plates of stamping quality. These usually do not possess sufficient resistance to abrasion and are not hard enough to be polished. (2) Three-layer steels overcome these disadvantages because the middle layer is of soft mild steel and the outer layers are of high-carbon steel containing chromium, nickel, or manganese. The layers are welded by hot rolling or by casting hard steel on a soft slab. On water-quenching, the external layers attain 700 Brinell.—R. S.

Nickel Saved by Substituting 430 for 18–8. (*Iron Age*, 1951, **168,** Dec. 13, 144). Details of the properties of type 430 chromium stainless steel are given and compared with Cr–Ni grades. Ductility is only about half ; high-temperature strength is rather less, but it does not work-harden as severely and thus is not subject to stress cracking after drawing.

Boron Steels Supplement Scarce Nickel, Moly Alloys. D. H. Ruhnke. (*Steel*, 1952, **130,** Jan. 14, 66–75). Now well beyond the experimental stage, boron steels are finding widespread applications throughout the automobile and allied industries. The selection of these steels as alternatives to other alloys is discussed and test data are examined. The hardenability patterns for several boron alloys are given, and it is stressed that, although they will fully harden in light sections, there will be more variation in hardness at a distance below the surface than with other alloy equivalents.—A. M. F.

High Strength Bolts—Better Fatigue Resistance for Structural Joints. (*Steel*, 1951, **129,** Dec. 24, 60–62). For structural joints, high-strength bolts are compared with cold- and hot-driven rivets. They are useful for structures subjected to widely fluctuating dynamic loading and for those subject to static loading. Although the cost is necessarily higher than for rivets, savings in the cost of installation can sometimes more than make up the difference.—A. M. F.

A Non-Shrinking Air-Hardening Steel. (*Edgar Allen News*, 1952, **30,** Jan., 32–33). The properties, uses, and heat-treatment of Double Seven, an air-blast hardened alloy steel for shear blades, dies, and heavy-duty punching are given, but no composition is stated.—R. A. R.

On the Stress–Strain Diagram of Time-Piece Spring. T. Mitsuhashi, R. Nakagawa, and S. Saito. (*J. Mech. Lab.*, 1951, **5,** Oct., 247–251). [In Japanese]. The permanent set of a clock spring was investigated by studying the stress–strain curve of a high-carbon steel wire under repeated loading in the elastic range. A special testing machine was used. The set was due to fatigue and not to creep.—J. G. W.

Study on Materials of Ball Bearing. E. Hayashi and S. Demachi. (*J. Mech. Lab.*, 1951, **5,** Sept., 188–191). [In Japanese]. Micrographic examination of Japanese ball-bearings revealed the presence of bad carbide segregation, hair-line cracks after lapping, and incorrect annealing procedure.—J. G. W.

Developments in the Use of Stainless Steel. J. L. Cotsworth. (*Iron Steel Eng.*, 1951, **28,** Nov., 66–68). A brief review is given of the developments and progress made in the manufacture of stainless steels both in Europe and the U.S.A. in the last 40 years, and production figures for a number of countries are given. The author discusses the corrosion and heat-resisting qualities of stainless steels. Brief metallurgical details are given, and physical and chemical properties considered.—M. D. J. B.

Carbon Steel Structural Sections and Steel Sheet Piling. (Amer. Iron Steel Inst. : *Steel Products Manual Section* 4, Jan., 1952). This 68-page booklet gives particulars of the standard angles, channels, tees, and **Z** bars rolled in the U.S.A.—R. A. R.

Carbon Steel Plates and Rolled Floor Plates. (Amer. Iron Steel Inst. : *Steel Products Manual Section* 6, Jan. 1952). This 65-page booklet gives descriptions, manufacturing practices, quality and chemical requirements, and tables of sizes and tolerances of the above plates in accordance with American practice.—R. A. R.

Alloy Steel Plates. (Amer. Iron Steel Inst. : *Steel Products Manual Section* 7, Jan., 1952). This 54-page booklet makes available to purchasers, producers, and users, information on manufacturing processes, specifications, compositions, qualities, and sizes of alloy steel plates produced in the U.S.A.

What Type High Alloy for Castings Now ? E. A. Schoefer. (*Indust. Heating*, 1951, **18,** Oct., 1799–1807). The author discusses three main classes of heat- and corrosion-resistant alloys, the use of which is made necessary by the shortage of nickel. The three types he considers are chromium, iron–chromium–nickel, and nickel–chromium alloys.—J. A. L.

Impact Properties of Stainless Steel and 9% Nickel Steel after Exposure under Stress to Liquid Nitrogen. T. N. Armstrong and A. J. Miller. (*A.S.T.M. Bull.*, 1951, Oct., 35–36). Tests were carried out on types 310 and 316 stainless steels and 9% nickel steel. Specimens were prepared from stainless steels in the annealed condition and from butt-welded pieces. The nickel steel was double-normalized and reheated to 1050° F., and butt welds were made. A jig of the same material as that tested was constructed, and a tensile stress of 30,000 lb./sq. in. was applied, the jig being immersed in liquid nitrogen. Impact properties were not affected when the stainless steels were exposed for two weeks and the nickel steel for two months.—B. G. B.

Studies on Steel Piston Ring.. M Kuroda and K. Kato. (*Rep. Sci. Res. Inst.*, **27,** 4, 285–292). [In Japanese].

Carbon Steel Wire. (Amer. Iron Steel Inst. : *Steel Products Manual Section* 16, 1952, Jan.) This 183-page manual gives

information on manufacturing practices, coarse and fine wire, evaluation of wire, and chemical requirements of carbon steel wire as produced in the U.S.A. A useful table presents comparative data on diameters, sectional areas, and weights of two American and two British wire gauges.—R. A. R.

Residual Stress of Drawn Steel Pipe. I—Preliminary Investigations. S. Sakui. (*Rep. Sci. Res. Inst.*, **27**, 4, 300–308). [In Japanese].

Developments in Steel Pressure Pipes. D. Cecchi. (*Costruzioni Met.*, 1951, **3**, Nov.–Dec., 21–26). [In Italian]. A review is given of recent developments in pressure pipes for hydro-electric schemes. Mild-steel pipes are being superseded by high-tensile steel pipes (55 kg./sq. mm.) that can be electrically welded. Welding techniques and methods of stress-relieving are also considered.—M. D. J. B.

Some Experience with Boiler Plate in Penstock Construction. W. Müller. (*Sulzer Tech. Rev.*, 1951, No. 2, 12–24). This article is drawn from practical experience and cites various examples of the difficulties encountered in the employment of steel plate for the construction of high-pressure pipelines. Recent progress in the development of high-strength structural steels and welding methods is described.—T. E. D.

Steel Wire. F. Jenks. (*Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 337–358). The history, manufacture and use of steel wire are discussed. The physical characteristics, obtained by judicious combination of chemical composition, heat-treatment, and subsequent cold work, are outlined.—J. P. S.

Steel Wire Ropes for the Mining Industry. W. Anderson. (*Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 301–336). The following are among the aspects dealt with: History; rope-making terms; wire-rope materials; characteristics affecting economy, operating life, and serviceability of a rope; and properties of wire rope and stresses occuring in wire ropes.—J. P. S.

Elasticity in Wire Ropes. (*Wire Production*, 1951, **1**, Dec., 24–25). This is a brief review of recent papers on the calculation of wire-rope stresses, from which it appears that no definite value can be laid down for Young's modulus of wire ropes, as it depends on rope construction, history, and application.—J. G. W.

Electronic Inspection Applied to Winding Ropes. O. P. Hansom. (*Wire Production*, 1952, **1**, Mar., 6–7).

Wire in Prestressed Concrete. (*Wire Production*, 1951, **1**, Dec., 28–34). This is an account of the manufacture of prestressed concrete tanks in the U.S.A., based on a report by M. R. V. Daviss. Steel wires (0·60–0·70% C) with a min. ultimate tensile strength of 210,000 lb./sq. in. are used.—J. G. W.

Wire in Brush Making. (*Wire Production*, 1951, **1**, Dec. 34–37). Attention is drawn to the great scope for wire in brush-making, and particulars are given of various types of brush in use. Stainless-steel wire is used for brushes for cleaning stainless steel, to avoid corrosion when brush particles cling to the parts.—J. G. W.

New Alloy Economy Steels Will Save Nickel and Molybdenum. (*Machinist*, 1951, **95**, Dec., 22, 1956–1957). British Standards Institution have issued eight new specifications for case-hardening alloy steels as an addendum to B.S. 970 : 1947. As an emergency measure, these new steels, which are 351 to 355 and 361 to 363 in the En series, are intended to replace the various alloy case-hardening steels in current use known as En 33, 34, 35, 36, 37, 38, 39, and 325.—E. C. S.

A Super Steel that Pays in the Long Run. (*Edgar Allen News*, 1951, **30**, Dec., 2–3). The article deals with the properties and treatment of a special alloy super die steel, known as Double Six, which Edgar Allen and Co., Ltd. has developed for use in specially long runs or other severe service.—E. C. S.

Vanadium Steels for Castings—Higher Tensile and Impact Strengths. (*Alloy Metals Review*, 1951, **8**, Dec., 2–6). Steel castings containing vanadium have a higher elastic ratio, a considerably higher impact strength, and, sometimes, a higher wear resistance than castings without vanadium but of otherwise similar composition and heat-treatment. They possess at least equal ductility in tension. Grain size is markedly smaller and more uniform, while grain growth at heat-treatment temperatures is decidedly retarded. The properties and treatment of those vanadium steels which are in regular production are given.—E. C. S.

Steel Tubular Products. (Amer. Iron Steel Inst.: *Steel Products Manual Section* 18, Dec., 1951). This 232-page handbook gives comprehensive information on the manufacture, properties, and dimensions of steel tubes produced in the U.S.A.—R. A. R.

Forged Axles and Locomotive Forgings. (Amer. Iron Steel Inst.: *Steel Products Manual Section* 22, Dec. 1951). In this 82-page booklet particulars are given of specifications of the Association of American Railroads and the American Society for Testing Materials for locomotive forgings and rolling stock for steam, diesel, and electric railways, and also for industrial railway equipment.—R. A. R.

On Flattening Test of Steel Cylinder. R. Aida. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1**, Oct., 255–259). [In English]. The author investigated an alternative to the flattening test prescribed by the Japanese Department of Commerce and Industry for compressed and liquefied gas cylinders. He concludes that a similar test performed on a tube longer than four diameters is an effective substitute for testing the finished gas cylinder.—J. G. W.

On the Effect of the Difference in Heat Treatments on the Yielding of a Carbon Steel. T. Sutoki and K. Saito. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1**, Oct., 143–147.) [In English]. A eutectoid steel was quenched and tempered, and austempered in such a manner that both treatments should result in a troostitic structure with the same hardness. The austempered specimens differed from the others in showing no yield point and greater ductility and toughness. The differences between the two groups of specimens support the author's theory of the yield-point phenomenon.—J. G. W.

Impact, Tensile and Hardness Tests of Some Ferrous Alloys, Including the Welded Parts, at Low Temperatures. T. Fukuroi, G. Monna, N. Ishii, and Y. Okamatsu. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1**, Aug., 101–105). [In English]. Mechanical tests revealed that austenitic chromium–manganese steel has very great toughness down to the temperature of liquid nitrogen. Two low-carbon steels and 2·5% Cr 0·363% Mo steel were also investigated.—J. G. W.

Reinforcing Concrete Bar Quality and Design. H. W. Bullard. (*Amer. Iron Steel Inst. Regional Meeting*, 1951). The author briefly describes recent improvements in the quality and design of concrete-reinforcing bars. The work of an American Iron and Steel Institute committee on the standardization and development of reinforcing bars is discussed.—G. F.

Bond Strength of Concrete Reinforcing Bars. (*Engineer*, 1952, **193**, Feb. 8, 226–227). Hooked concrete reinforcing bars have never been popular in the U.S.A. and this article describes work carried out to determine which of 17 different types of 'deformed' bar provides the best bond. The bars tested had ridges, ribs, or other projections. These deformed bars give greater bond strength than plain rounds, and the best results were obtained with bars complying with A.S.T.M. Specification A305-49.—M. D. J. B.

Stainless Steel Product Standards. G. N. Malcolm. (*Iron Steel Eng.*, 1952, **29**, Jan., 70–72). After defining size standards for flat-rolled products, sheet, strip, plate, and coils, the author considers standards of finish with special reference to stainless steel. Hot- and cold-rolled products and the annealing, pickling, and polishing processes are examined.—M. D. J. B.

Progress in Stainless and Heat Resisting Steels. J. Lomas. (*Eng. Boiler House Rev.*, 1951, **66**, Dec., 368–369). Some recent applications of stainless and heat-resistant steels are considered.—E. C. S.

Precipitation-Hardening Stainless Cuts Hand Work and Rejects on Aircraft Parts. F. R. Kostock. (*Western Metals*, 1951, Dec., 32–34). The difficulties experienced in forming aircraft parts in conventional stainless types of steel are discussed. The author then describes the good formability of a new stainless alloy designated 17–7 PH by the Armco Steel Corp. Typical parts produced in this material are illustrated, and its mechanical properties are compared with 18/8 stainless steel.—P. M. C.

Standards for the Australian Metals Industry. W. I. Stewart. (Australian Inst. Metals: *Australasian Eng.*, 1951, Dec. 7, 81–86). A brief survey is given of the present scope of standardization for the Australian metals industry.

Cast Metals in Construction. W. Hartmann. (*Z.V.d.I.*, 1952, **94**, Jan. 21, 65–73). The author discusses the relative merits of the use of steel and cast iron in the construction of machines. He points to the advantage of cast iron, with regard to the weight of pig iron per unit weight of finished part, and to its rigidity and ease of design. He compares

forged with cast crankshafts and welded with cast housings on cost grounds.—J. G. W.

Properties and Applications of Ductile Iron. G. L. Cox. (*Iron Steel Eng.*, 1951, **28**, Dec., 75–83). The tensile properties, chemical composition, and specifications of ductile iron are considered in detail, together with chemical and physical control, annealing and heat-treatment properties, effect of section size on properties, surface condition, resistance to impact, impact at low temperatures, compressive strength damping, galling and wear properties, machinability, surface hardening, pressure tightness, corrosion resistance, and steel-mill uses.—M. D. J. B.

Fatigue Strength of Nodular Iron Tested. T. E. Eagan. (*Iron Age*, 1951, **168**, Dec. 13, 136–139). This paper reports tests that have been carried out on specimens of nodular iron cut from both standard cylinders and actual castings. Endurance ratio for the material is approx. 0·34. A 0·050-in. notch reduces fatigue strength by a factor of 1·3 for heat-treated material, 1·45 for as-cast. Elongation is usually lower in castings than in keel blocks.—A. M. F.

Irons Containing Spheroidal Graphite. J. Grilliat. (*Ingénieurs et Techniciens*, 1952, Jan., 21–28). The effects of the form of the graphite on the properties of cast iron are given. The use of nodular cast iron to replace grey iron, malleable iron, and cast steel is discussed.—T. E. D.

Ductile Cast Iron. M. M. Hallett. (*Trans. Inst. Marine Eng.*, 1952, **64**, Feb., 25–30). The microstructure, mechanical properties, physical properties, and properties depending on surface condition of spheroidal graphite cast irons are comprehensively summarized. Ductile cast irons with an austenitic, pearlitic, or ferritic matrix are considered. Original experimental results are quoted, and are supplemented by published data. Production properties are discussed from the point of view of the foundry and machine shop, and possible applications in marine engineering are indicated.—T. E. D.

Physical and Mechanical Properties of Cast Iron. W. L. Collins. (*Mech. Eng.*, 1951, **73**, Dec., 979–982). The paper is based on the information as to the mechanical and physical properties of cast iron given in a recent booklet "Engineering Properties of Cast Iron," issued by the American Foundrymen's Society.—D. H.

Statistical Consideration of the Strength of Cast Iron. G. Meyersberg. (*Arch. Eisenhüttenwesen*, 1951, **22**, Nov.–Dec., 377–385). Weibull has shown that it is possible, by applying the laws of probability and taking account of lattice defects, to represent the effect of specimen size on the results of tensile testing by the formula

$$S = 1 - \exp\left[- V\left(\frac{\sigma - _{\mu}\sigma}{\sigma_0} \right)^m \right]$$

where S is the fraction of specimens ruptured under a stress σ, V is the volume of the specimens, and σ_μ, σ_0, and m are constants. Some considerations to explain the nature of these constants are advanced. The exponent m is characteristic of the material and indicates the manner of interaction of the defects; σ_0 defines the height of the region of stress and σ_μ is the threshold stress beyond which rupture is possible. Procedures for evaluating these constants are given. Besides the influence of size, there is also a margin effect. This characterizes the phenomenon in cast iron, that tensile specimens with different diameters but the same structure show a decrease of tensile strength when the diameter is below a certain limiting value. These theoretical considerations have been supplemented by tests to evaluate the influence of size and margin. For these, specimens were of cast iron, the structural uniformity of which had been demonstrated. Bend, torsion, and wedge indentation tests were carried out. From the results of these tests, the values of the constants in the Weibull formula were calculated. The exponent m can be regarded as a unique characteristic of the material, if the stress distribution in the specimen is uniform. This is true for tensile specimens. The results of other types of test must therefore be converted to tensile stresses.—J. P.

Austenitic Cast Iron. J. Wojcik, J. Gepner, and M. Pachowski. (*Przeglad Odlewnictwa*, 1951, **1**, Nov., 311–317). [In Polish]. The general characteristics of austenitic cast iron, the technology of its manufacture, its structure, mechanical properties, machinability, and resistance to high temperatures are described.—V. G.

Nodular Iron Hot-Forged and Rolled Experimentally. J. A. Perry and J. E. Rehder. (*Iron Age*, 1951, **168**, Oct. 4, 229–233). Nodular iron has been rolled and forged on a laboratory scale to give structures and properties not obtainable when cast. High rolling temperatures and increased reduction improve mechanical properties, but edge cracking reduces the usable width by 80%.—A. M. F.

Effect of Phosphorus Content on Mechanical Properties of a Nodular Cast Iron. J. E. Rehder. (*Trans. Amer. Found. Soc.*, 1951, **59**, 501–508). The idea that it is desirable to have a low phosphorus content in nodular irons if the highest ductility and impact strengths are to be obtained is confirmed quantitatively for the as-cast, fully annealed, and oil-quenched and tempered states. Phosphorus retards graphitization and causes the pearlite lamellæ to become finer as its content is increased.—P. C. P.

Influence of Silicon Content on Mechanical and High-Temperature Properties of Nodular Cast Iron. W. H. White, L. P. Rice, and A. R. Elsea. (*Trans. Amer. Found. Soc.*, 1951, **59**, 337–347). The limited usefulness of growth-resistant 6% silicon iron due to its brittle nature is mentioned, and attempts to overcome this by converting the flake graphite into the spheroidal type are described. Results show that spheroidal 4–5% silicon cast irons have sufficient impact resistance to be free from extreme brittleness. The growth of 6% silicon iron containing spheroidal graphite is almost immeasurable.—P. C. P.

Report on Nodular Cast Iron. (*SAE J.*, 1951, **59**, Dec., 23, 24, 26). The properties, castability, and general applicability of nodular iron are compared very briefly with grey iron, malleable and pearlitic irons, and with steel.—P. M. C.

Cast-Iron Crankshafts, with Special Reference to Acicular and Spheroidal-Graphite Cast Irons. A. B. Everest. (Congrès International des Moteurs: *Foundry Trade J.*, 1951, **91**, Dec. 6, 643–650). The author discusses cast *versus* forged crankshafts, especially the advantages and disadvantages of the former. He deals also with alloy cast irons, including acicular cast iron for Diesel engine crankshafts, test data of cast-iron crankshafts, and the possibilities of using spheroidal-graphite cast irons.—E. T. L.

Applicability of Pig Iron Produced Under High Aluminous Slag. N. Hajtó and F. Varga. (*Acta Technica Academiae Scientiarum Hungaricae*, 1950, **1**, 1, 5–21). [In English]. As the entire home production of Hungarian pig iron is used for steelmaking, grey cast iron processed in the small blast-furnace of Diósgyör under a calcium aluminate slag, commonly termed 'bauxite pig iron,' is important. Its properties were examined and compared with those of Swedish and Austrian charcoal pig irons. The bauxite pig iron was found to be of comparable quality and suited for grey and malleable castings, the only drawback being the variable silica content (0·8–2·2%).—P. F.

METALLOGRAPHY

The Electron Microscope in Metallurgy. H. Mahl. (*Metall*, 1952, **6**, Feb., 69–73). Methods for obtaining replicas of metal surfaces are described, illustrated, and compared. The problem of locating a selected area is also discussed.—J. G. W.

On the Electron Microscopic Structure of the Graphitic and Temper Carbon in Cast Iron. H. Sawamura. (*Memoirs, Faculty of Engineering, Kyoto Univ.*, 1951, **13**, Oct., 209–211). [In English]. The size and shape of kish graphite, and of graphitic and temper-carbon in cast iron, extracted from grey cast iron, ductile cast iron, and black-heart malleable iron were investigated. Electron micrographs were taken after ultrasonic dispersion of the samples in water. These reveal a large proportion of crystals much bigger than those measured by Wever in 1922.—J. G. W.

Comparative Examination of Methods for Making Visible the Grain Size of Austenite. F. Hajtó. (*Acta Technica Academiae Scientiarum Hungaricae*, 1951, **1**, 3, 183–189). [In German]. Measurements of the grain size of austenite formed in the 800–1150° C. range were carried out by etching and observation of the ferrite network that precipitates on the austenite grain boundaries on cooling rapidly; observation of the troostite network visible at a certain distance from the quenched end in an end-quenched specimen; fractography; and the McQuaid–Ehn method. There was little difference in the results. The carburization involved in the McQuaid–Ehn test did not noticeably influence the grain size.—P. F.

Cathodic Etcher. (*Metal Ind.*, 1952, **80**, Jan. 18, 53). A new metallographic technique, which should prove particularly

useful for studying grain structure and cold flow lines, has been developed by Distillation Products Industries, a division of the Eastman Kodak Co., New York. The metal sample is bombarded with a glow discharge at certain low pressures, 'etching' of the surface being produced by positive ions passing between an aluminium anode and the specimen under test. The etching is thus produced physically rather than chemically, and greater clarity results.—P. M. C.

Microstructure of Tinplate. T. Fielding. (*Tin-Printer and Box Maker*, **28,** 1952, Feb., 8–9). Tin belongs to the tetragonal lattice system. To obtain a microsection of tinplate, the specimen is degreased and plated with a heavy deposit of copper. After plating, the specimen is sectioned, mounted, and polished with down to 000 emery paper. After final polishing, the specimen is etched in either alcoholic ferric chloride solution or a 5% aqueous solution of ammonium persulphate. This is the method due to Taffs. The method of Romig and Rowland and a simplified method for routine laboratory work are also described.—J. P. S.

Microstructural Changes in the High-Alloy Valve Steel XCR. B. Cina. (*J. Iron Steel Inst.*, 1952, **171,** July, 229–237). [This issue].

Note on the Preparation of Metallic Single Crystals. F. Bouillon. (*Bull. Soc. Chim. Belges*, 1951, **60,** Sept.–Oct., 333–336). A method is described in which single crystals are formed by the slow solidification of the molten metal. The furnace and the method of controlling the slow cooling are described and shown diagrammatically.—T. E. D.

The Classical Picture of Recrystallisation after Work Hardening. D. I. Cameron and A. Stein. (*Proc. Australasian Institute of Mining and Metallurgy*, 1947, Apr.–June, 15–30). The work described on low-carbon steel emphasizes the necessity for careful examination of annealing conditions in the temperature range 550–750° C. The times of annealing for complete recrystallization can cover a very wide range for a series of deformations and temperatures; some typical times are given. The indeterminate area between hot work and cold work has been examined, and an experimental method is suggested for determining the effects of residual work-hardening from semi-hot work by a combination of cold rolling and annealing. Grain growth in low-carbon steel is associated with a combination of semi-hot and cold work, which is only found at annealing temperatures of 650° C. and above, or during a very slow rise to about 600° C. A lower heating temperature before the semi-hot work eliminates this increase in grain size. The inhibiting effect of previous annealing is shown by means of micrographs.—J. P. S.

Methods of Preparing and Examining Large Metallic Crystals. P. Lacombe. (*Métaux-Corrosion-Indust.*, 1951, **26,** Oct., 392–409). Several different methods for preparing single crystals or polycrystalline specimens composed of large crystals are explained. The choice of a particular method must be determined, not only by the required crystal size, but also so as to obtain the most perfect crystal structure. Owing to segregation phenomena, the methods based on solidification are not suitable for preparing crystals of alloys or solid solutions.—B. G. B.

The Diffraction of X-Rays by Distorted-Crystal Aggregates. III—Remarks on the Interpretation of the Fourier Coefficients. J. N. Easterbrook and A. J. C. Wilson. (*Proc. Phys. Soc.*, 1952, **65B,** Jan. 1, 67–75). The problem of obtaining the greatest possible amount of information from observed line profiles of all orders is discussed. Usually, only a few orders can be measured, yeilding little information, but in three special cases, the Fourier coefficients of two lines can yield all the information obtainable from the full set.—C. J. B. F.

The Crystallographic Aspect of Slip in Body-Centred Cubic Single Crystals. I—Theoretical Considerations. A. J. Opinsky and R. Smoluchowski. (*J. Appl. Phys.*, 1951, **22,** Nov., 1380–1384). The mechanism of slip in body-centred cubic lattices is considered in terms of the relation between the orientation of the tensile axis and the active slip system. A 'projection' of points in the unit stereographic triangle on its [001]–[011] side permits an analysis of experimental data, and leads to an accurate determination of the ratio of the critical shear stresses on various planes.—J. P. S.

Structure of Metallic Materials. K. Wellinger. (*Z.V.d.I.*, 1952, **94,** Mar. 1, 177–184). This is an elementary account of crystallography and metallography for engineers.—J. G. W.

Concerning the Migration of Grain Boundaries of Austenite. M. G. Lozinskii. (*Doklady Akadmii Nauk S.S.S.R.*, 1952, **82,** No. 1, 53–56). [In Russian]. A method and apparatus for the investigation of kinetics of migration of the grain boundaries of austenite in steel are described.—V. G.

About the Influence of Deformation on the Kinetics of Martensite Transformation. O. P. Maksimova and A. I. Nikonorova. (*Doklady Akademeii Nauk S.S.S.R.*, 1951, **81,** 2, 183–186). [In Russian]. The effect of deformation on the velocity of martensite transformation during cooling of nickel and manganese steels was investigated.—V. G.

Transformation Diagrams of Constructional and Tool Steels. M. Kroneis and H. Krainer. (*Betrieb u. Fertigung*, 1952, **6,** Feb., 21–27; Mar., 41–48). Isothermal transformation diagrams are reproduced for a range of nine alloy constructional steels and 16 tool steels made by Gebr. Böhler & Co., A.G., Kapfenberg, Austria. The chemical compositions, trade names, and applications are given.—R. A. R.

The Position of the Ar_3 Point in Stainless Chromium–Nickel Steels and Its Displacement by Cold Working. P. Bastien and J. Dedieu. (*Métaux-Corrosion-Indust.*, 1951, **26,** Nov., 423–426). Two experimental techniques were used and are described; one, a didatometric method, and the other a magnetic method. The position of the Ar_3 point varies from + 200° C. with 4% Ni to − 200° C. with 11% Ni. The effect of cold working is discussed.—B. G. B.

On the Formation of Superlattice in Binary Body-Centred Cubic Alloy. K. Adachi. (*Sci. Rep. Tôhoku Univ.*, 1951, **35,** Apr., 30–40). [In English]. The author develops Matsuda's theory of the formation of the A_3B type superlattice in a body-centred cubic alloy by treating the influence of second neighbour interaction on superlattice formation with Matsuda's special assumption of special sublattices. The theoretical results are compared with experimental data for the Fe–Al alloy and show good agreement for an interaction ratio of about 0·4, if one allows for the effect of ferromagnetism which is not taken into account in the theory.—J. G. W.

Transformation of Low-Carbon, 12% Chromium Stainless Steels. A. E. Nehrenberg. (*Metal Progress*, 1951, **60,** Nov., 64–69). Quantitative data is presented to show the variation in amount of δ-ferrite with temperature in 12·5% chromium stainless steels containing 0·06, 0·10 and 0·12% of carbon. In order that the study would cover most of the variations likely to be encountered in practice, heats of low, intermediate, and high attainable hardness were included.—J. P. S.

On the Theory of Formation of Ferromagnetic Superlattice Alloys. H. Sato. (*Sci. Rep. Res. Inst. Tôkohu Univ.*, A, 1949, **1,** May, 71–82). [In English]. A statistical theory of ferromagnetic superlattice based on the Bragg–Williams approximation is compared with one based on Sato's approximation. The latter is also applied to anti-ferromagnetism. The theory deals successfully with several anomalies of the superlattice structure.—J. G. W.

On the Behaviours of Enormously Large Internal Stress Accompanying the Transformation of a Substance. K. Honda. (*Sci. Rep. Res. Inst. Tôhoku.*, A, 1949, **1,** May, 1–6). [In English]. The author draws attention to the difference between the heating and cooling curves of the A_3 point with increasing nickel content in iron–nickel alloys, and explains it in terms of the large stresses arising from the volume change of the α–γ transformation. Similar reasoning is applied to the behaviour of iron–manganese alloys.—J. G. W.

On the Mechanism of the Formation of Pearlite in Steels. K. Honda. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** May, 7). [In English]. The view is put forward that the mechanism of pearlite formation is the precipitation of cementite along slip bands formed as the result of pressure which accompanies the change in volume during the γ–α transformation.—J. G. W.

A Note on the Formation of Undercooled Graphite in High-Purity Fe–C–Si Alloys. W. S. Owen and B. G. Street. (*J. Iron Steel Inst.*, 1952, **171,** July, 237–238). [This issue].

On γ–α Transformation in Fe–Ni Alloys by Supercooling or Superheating. S. Takeuchi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** May, 43–49). [In English]. It is concluded, from an experimental study of the A_3 transformation and phase boundary between the γ and α phases of Fe–Ni alloys, that on cooling or heating with a marked hysteresis, the lattice alone can be transformed without any change of concentration. This lattice transformation occurred only when the alloy was superheated or supercooled beyond the co-existing region of two phases. The equilibrium diagram of the alloy in the solid state was drawn from the temperatures of lattice transformation.—J. G. W.

On the Velocity of Decomposition of Cementite. H. Yoshisaki. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** May, 63–69). [In English]. The coefficient of reaction velocity of cementite decomposition is defined rationally, and the constant K occurring in the equation was evaluated with the aid of dilatometric measurements. From these, an empirical formula for the dependence of K on temperature and composition was derived.—J. G. W.

An Investigation on Isothermal Transformation in Steels. I—The Cause of Modification of S-Curves in Some Alloy Steels. T. Murakami and Y. Imai. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Aug., 87–92). [In English]. The velocity of isothermal transformation of 0·4% C steels containing about 1% tungsten, molybdenum, chromium, aluminium, tin, vanadium, or cobalt, and 0·31% of titanium, was measured, and the **S**-curves were determined. Modifications of the **S**-curves are due to the separation of different carbides.—J. G. W.

Decarburized Structures in Steels. K. Iwasé and T. Mochida. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Aug., 93–94). [In English]. Three different structures are found in decarburized layers, and are illustrated. The authors explain their appearance by reference to the equilibrium diagram and occurrences during transformation.—J. G. W.

Abnormal Steel and Its Structure. K. Iwasé and M. Homma. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1,** Aug., 695–700). [In English]. Abnormal structures appearing in decarburized steel have been studied by the authors, who seek to explain them by local changes in carbon concentration during the γ–α transformation.—J. G. W.

On the Behaviour of Metals during Rapid Heating and Rapid Cooling (II). S. Sakui. (*J. Sci. Research Inst., Tokyo*, 1950, **44,** June, 139–150). [In English]. Transitional structures in eutectoid steels, such as occur during rapid heating and rapid cooling, were investigated by X-ray, hardness, electric resistance measurements, and by microscopy. Two transitional structures were discerned : (i) A mixture of martensite, troostite, and a trace of austenite softer than martensite ; and (ii) pure acicular martensite, with smaller traces of austenite, and intensely hard. Calculations of the rate of transformation of AC_1 were in fairly good agreement with experimental data. The author concludes that in high-frequency surface hardening of sorbitic structures the first type of structure need not be taken into consideration.—J. G. W.

Research on Phase Transformations in the Iron–Platinum System. A. Kussmann and G. v. Rittberg. (*Z. Metallkunde*, 1950, **42,** Dec., 470–477). Electric, dilatometric, magnetic, and X-ray methods were used to examine the Fe–Pt system. A ferromagnetic phase Fe_3Pt was discovered in the region 45–63% Pt (by weight), unaccompanied by the generally observed changes in electrical conductivity. An $FePt_3$ phase was observed in the region 94–98% Pt, and a narrow ferromagnetic region was found quite close to the 100% platinum end. The correct value of the c/a ratio of the face-centred tetragonal lattice of FePt was found to be 0·973.—P. F.

Method of Representation of Five-Component and More Complicated Systems. I. I. Kornilov. (*Doklady Akademii Nauk, S.S.S.R.*, 1951, **81,** 2, 191–194). [In Russian]. A graphical method of presentation of complicated metallic systems is proposed.—V. G.

New Intermetallic Compound in Binary System Iron-Molybdenum. R. P. Zaletaeva, N. F. Lashko, M. D. Nesterova, and S. A. Yuganova. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **81,** 3, 415–416). [In Russian]. The existence of the compound Fe_2Mo is claimed. The crystallographic structure of this compound is similar to Fe_2W.—V. G.

On the Structural Diagram of Cast Iron. M. Maruyama. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2,** Oct., 758–763). [In English]. A new diagram is proposed in which allowance is made for the effect of cross-section on structure. Ranges of structure for various silicon contents are shown and the effects of carbon and silicon are compared.—J. G. W.

Modes of Decomposition of the Ferrous Oxide Phase. R. Collongues and G. Chaudron. (*Compt. Rend.*, 1952, **234,** Feb. 11, 728–729). Between 480° and 570° C. ferrous oxide undergoes ' pearlitic ' decomposition to alternate lamellæ of iron and magnetite, the lamellæ being largest near 570° C. and the rate of decomposition a maximum at 480° C. In this temperature range, iron and magnetite precipitate simultaneously, the ferrous oxide having the constant lattice parameter, $a = 4{\cdot}287$ Å.—A. G.

Contribution to the Study of the Morphology of Non-Metallic Inclusions in Iron and Steel Products—Inclusions in Ferro-tungsten. R. Zoja and M. T. Gottardi. (*Met. Ital.*, 1951, **43,** Dec., 526–529). Eighty-nine specimens taken from 29 different samples are examined, and many papers on the characteristic inclusions of ferro-alloys are cited. The result of this investigation has been to distinguish these inclusions from those in ferrochromium.—M. D. J. B.

Intermediate Phases in Ternary Alloy Systems of Transition Elements. S. Rideout, W. D. Manly, E. L. Kamen, B. S. Lement, and P. A. Beck. (*Trans. Amer. Inst. Min. Met. Eng.*, 1951, 872–876 ; *J. Met.*, 1951, **3,** Oct.). The authors present the results of an investigation of the 1200° C. isothermal sections of the ternary phase diagrams Cr–Co–Ni, Cr–Co–Fe, Cr–Co–Mo, and Cr–Ni–Mo. In all four systems, the σ phase is found to form extended fields of ternary solid solutions, and this fact is discussed and interpreted in terms of electron vacancy concentrations. In both the Cr–Co–Mo and Cr–Ni–Mo systems, new ternary phases have been located.—G. F.

The Cast-Iron–Steel Limit Alloy. G. Bruni. (*Met. Ital.*, 1951, **43,** Oct., 435–438). There are two fundamental types of saturated austenite, $Fe_{12}C$ and $Fe_{13}C$. This composition is in relation with the γ iron lattice, with alternate layers of four and five atoms forming Fe_{13} and Fe_{14} groups. $Fe_{12}C$ decomposes generating Fe_3C cementite and Fe_9 groups ; $Fe_{13}C$ precipitates its own carbon and forms a group (Fe_{13}) compatible with the lattice structure of the iron. The molecules of the above carbides unite and form $Fe_{12}C.Fe_{13}C.Fe_{12}C$ and $Fe_{13}C.Fe_{13}C.Fe_{13}C$ groups, as found when the graphite and ledeburite eutectics were deposited. (20 references).—M. D. J. B.

Is There a Continuous Transition from Pro-Eutectoid Ferrite or Cementite to Pearlitic Ferrite and Pearlitic Cementite Respectively ? S. Modin. (*Jernkontorets Ann.*, 1951, **135,** 4, 169–174). [In Swedish]. Microscopic examinations indicate that in hypo-eutectoid steels, pro-eutectoid ferrite is often continuous with pearlitic ferrite. This is contrary to observations reported by Mehl. Pro-eutectoid cementite is observed to have a ferrite border that makes it distinguishable from ordinary pearlite.—B. S. E.

Influence of Nickel on the Diffusion of Carbon in Austenite. M. E. Blanter. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20.** 2, 217–221). [In Russian]. A study of the influence of nickel content (0–18%), carbon concentration (0·2, 0·4, and 0·7%), and temperature (1000–1200° C.) on the diffusion of carbon in austenite is reported. The diffusion coefficient increases continuously with increasing nickel content. This is because the heat of diffusion decreases with increase in nickel concentration. This indicates that the carbon bond energy in the austenite lattice is reduced by alloying nickel. The equations relating the diffusion coefficient with temperature for different nickel percentages are given.—V. G.

Study of the Iron–Phosphorus Diagram and of the Phosphorus Grain Test. P. Rocquet and G. Jegaden. (*Rev. Mét.*, 1951, **48,** Sept., 712–721, Oct., 793–810). The limits of the γ-phase for the iron–phosphorus system have been determined. To estimate phosphorus content during the making of Bessemer steels, a small ingot is cast, stripped, and then forged into a disc at a temperature between 1300° and 1110° C. This is quenched from 1000° C. and fractured ; characteristic lines are then observed, owing to the stability of nuclei of the α-phase on reheating, which leads to a reappearance of the primary as-cast structure on cooling. Lines are only visible down to a phosphorus content of 0·08%, and, although this limit can be lowered by the addition of a third element, *e.g.*, 3% tungsten, this is not easy in the steelworks.—A. G.

Iron/Iron-Sulphide/Ferrous-Oxide System. Ya. I. Ol'shanskii. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **80,** 6, 893–896). [In Russian]. The ternary system Fe–FeS–FeO is discussed, and the diagram is given with the plots of the points obtained in the author's experiments.—V. G.

Micrographic Study of the Oxidation of Iron and the Transformations of Ferrous Oxide. G. Chaudron and R. Collongues. (*Rev. Mét.*, 1951, **48,** Dec., 917–922). A thick layer of ferrous oxide is produced by oxidation with hydrogen and steam. Each crystal of FeO is made up of blocks of slightly different orientation. Decomposition below 570° C. begins by precipitation of iron at the edges of grains and blocks, followed by intergranular precipitation and rapid coalescence of small iron crystals.—A. G.

CORROSION

Progress in the Prevention of Corrosion. W. H. J. Vernon. (*Australasian Eng.*, 1951, Dec. 7, 73; *Metall*, 1952, **6**, Feb., 73–74). A very brief note on the most recent progress made in the development of vapour-phase inhibitors, microbiological corrosion inhibitors, and in the treatment of environment.—P. M. C.

An Unusual Specialist: The Anticorrosion Engineer. A. J. Maurin. (*Ingénieurs et Techniciens*, 1951, Nov., 553–559; Dec., 613–620; 1952, Jan., 29–36; Feb., 19–25; Mar. 41–44). The knowledge, importance, and field of action of this specialist are surveyed. Electrochemical corrosion mechanisms are discussed, and the use of theoretical autocorrosion diagrams is explained. Measurements of potentials and *p*H are mentioned. Chemical oxidation of metals at high temperature is considered, and the principles of inoxidizability are discussed. Corrosion of common metals in pure and polluted atmospheres is tabulated. An outline is given of corrosion associated with the petroleum industry, the sea, and fresh water. Recommended precautions for diminishing corrosion are represented schematically. The mechanism of bacterial corrosion is given. Methods of passivating many common metals against corrosive agents are tabulated. Corrosion in pipes, boilers, and condensers is mentioned and also the effect of some lubricants on metal surfaces. The corrosion of submerged or buried pipes is surveyed and cathodic protection is explained. The effects of corrosion on the mechanical properties of metals and suitable resistant alloys are mentioned.—T. E. D.

Corrosion and Its Control in a Chemical Plant. C. W. Day. (*Chem. Eng.*, 1952, **59**, Jan., 155–157). The organization of testing procedure to combat corrosion is described. Special reference is made to gasket-joints, water treatment, underground pipes, and welding techniques.—T. E. D.

2nd Report of the Methods of Testing (Corrosion) Sub-Committee. (*J. Iron Steel Inst.*, 1952, **171**, July, 255–272). [This issue].

Technical Practices in Cathodic Protection. H. H. Anderson. (*J. Amer. Water Works Assoc.*, 1951, **43**, Nov., 883–896). This bulletin describes briefly the fundamentals of the application of cathodic protection. Details are given of the determination of the current required and of the location of the current supply points. The use of buried galvanic anodes of magnesium or zinc and the recent application of magnesium ribbon (laid parallel to the pipeline and thereby providing a continuously distributed anode) are discussed.—B. J. B.

The Corrosion of Metals in Hydrocarbon Solutions of Fatty Acids. L. G. Gindin and V. A. Kazakova. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **80**, 3, 389–392). [In Russian]. The corrosive influence on metals of benzene, iso-octane, petroleum ether, and other liquid hydrocarbons was investigated.—V. G.

Concerning Corrosion Fatigue. G. V. Karpenko. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **79**, 2, 287–288). [In Russian]. The author suggests that corrosion fatigue consists of two consecutive processes: (1) Adsorption and formation of fatigue cracks; and (2) the corrosion process proper. Data from experiments corroborating these views are given.—V. G.

Structural Changes Sabotage Corrosion-Resistant Liners. J. H. Van Swaal. (*Iron Age*, 1951, **168**, Nov. 8, 138–142). The changes that can occur in corrosion-resistant steels used as liner materials in the chemical and petroleum industry apparatus are described. Methods of preventing weld decay, carbide precipitation, and sigma-phase formation are given.

Corrosion Data of Welded Low-Carbon Stainless Steel. H. F. Ebling and M. A. Scheil. (*Welding J.*, 1951, **30**, Oct., 511s–518s). Corrosion resistance of welded, heat-treated alloys and weld deposits of unstabilized low-carbon 18/8 stainless steel were determined and compared with the stabilized grades, using the standard boiling nitric acid test. The low-carbon 304-type alloy was found to be equal or better in corrosion resistance than the stabilized grades after normal fabricating heat-treatments and for use where service temperatures do not exceed 800° F.—U. E.

High-Chromium Steels Resist Attack by Liquid Bismuth Alloys. J. L. Everhart and E. L. Van Nuis. (*Mat. Methods*, 1951, **34**, Oct., 112–114). Certain bismuth alloys (Bi–Pb, Bi–Pb–Sn, and Bi–In–Pb) can, in many instances, be used as very efficient liquid heat-exchange media. Their use, however, depends on the selection of suitable constructional materials to contain them. The high-chromium stainless steels are most resistant to corrosion, and the results of corrosion experiments are described.—P. M. C.

The Rate of Pickling Test for Tin-Plate Steels and Its Metallurgical Significance. E. L. Koehler. (*Amer. Soc. Met. Preprint* 7w, 1952). Poor internal corrosion resistance of tin cans is indicated by 'pickle-lag,' *i.e.*, an initially low rate of attack in pickling. It is due to grain-boundary oxides on the steel. Pickle lag may be conveniently determined by measuring the corroding potential of the steel specimen against a reference electrode also in hydrochloric acid.—E. T. L.

The Mechanism of Scale Formation on Iron at High Temperature. B. W. Dunnington, F. H. Beck, and M. G. Fontana. (*Corrosion*, 1952, **8**, Jan., 2–13). A new mechanism of high-temperature oxidation of iron is suggested. The diffusion process responsible for the formation of an oxide layer is assumed to be due to the movement of vacant lattice sites. Diffusion of these lattice vacancies influences the type of oxide formed. The oxide is produced either as an adherent film or as a thin, loose, more highly oxidized layer. On thin (0·16 cm.) specimens, the adherent film, growing according to the parabolic law, forms on one surface and the loose layer, following a pseudo-linear law, on the other. On thick specimens (½-in.), no continuous adherent film is formed, confirming Pfeil's work. Precipitates of Fe_3O_4 in slowly cooled FeO and of Fe_2O_3 in slowly cooling magnetite are described. In the latter it is shown that the precipitate forms on the [111] planes of the magnetite. Blisters formed by heating iron in air become covered by the oxide subsequently produced.—G. P. A.

ANALYSIS

Study of the Estimation of Silica in Lorrain Iron Ores. J. Baron. (*Chim. Analy.*, 1951, **33**, Dec., 333–340). A satisfactory method for the determination of silica has been evolved in the light of present knowledge. It is described in great detail. (25 references).—T. E. D.

Rapid Method for Determining Calcium and Magnesium in Dolomites, Magnesites, and Open-Hearth Slags. Iu. I. Usatenko and O. V. Datsenko. (*Zavodskaya Laboratoriya*, 1950, No. 1, 94–96). [In Russian]. A volumetric method is proposed for the determination of calcium and magnesium, the duration of the analysis being 1·5–2 hr. The method is based on the precipitation of the components being determined by standardized solutions of sodium oxalate and dibasic sodium phosphate, the excesses of which are then determined in an aliquot part of the filtrate by titration with permanganate and hydrochloric acid. For the acid titration, a mixed indicator with a very sharp colour change has been found.—S. K.

Rapid Photoelectric Method for Determining Phosphates in Basic Open-Hearth Slags. A. I. Masurova. (*Zavodskaya Laboratoriya*, 1950, No. 1, 96–97). [In Russian]. The proposed method for the determination of phosphates is based on the reaction of the formation of the yellow complex $H_7[P(Mo_2O_7)_6]$, followed by its reduction to molybdenum blue by sodium sulphite and bivalent iron. Satisfactory results were obtained, using a yellow-green filter for the photocolorimetric determination.—S. K.

Errors in Blast Furnace Slag Analysis and their Elimination. E. T. Saxer and E. W. Jones. (*Blast Furn. Steel Plant*, 1952, **40**, Feb., 208–214). A method is described for the volumetric determination of alumina in blast-furnace slag. An improved scheme is given for the determination of silica, lime, and magnesia in this sequence. The separation of titanium as the stannate, with subsequent colorimetric determination, is described.—J. P. S.

Quantitative Emission Spectrum Analysis. IV—Determination of the Silica–Lime Ratio in Basic Slag. S. Musha. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Oct., 741–747). [In English]. The method consists of placing the powdered sample in the cavity of a copper electrode without any adhesive agent, and making the emission against a second electrode of the same type. Exposure of 30 sec. was made without any preliminary discharge. The dry plate was developed in methanol for 1 min. and dried in air dryer for 2–3 min. Ca 4318·7 Å. (I)/Si 2881·6 Å. (I) was chosen as the line pair, and, by measuring its density, 2–4 of the lime/silica ratio was determined within 10% in under 1 hr.—J. G. W.

Rapid Volumetric Determination of Silicon in Iron and Steels and Silica in Slag and Rocks. H. Gotô and Y. Kakita. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1949, **1**, Oct., 175–

178). [In English]. Silicic acid was precipitated as potassium fluosilicate in HNO_3 and determined by a titration with a standard hydroxide after dissolving the precipitate in hot water. Iron and steel were dissolved in nitric acid, carbon that separated out oxidized with potassium chlorate, and then silicon was precipitated with potassium chloride and hydrofluoric acid as potassium fluosilicate. Basic slag was dissolved in HNO_3 directly ; the acidic slag after fusion with potassium carbonate. The time for this analysis is 17–25 min.—J. G. W.

On the Determination of Manganese in Ferro-Manganese and Minerals. M. Jean. (*Anal. Chim. Acta.*, 1950, **4,** Aug., 360–365). [In French]. The determination of manganese in iron by oxidation to the heptavalent state with persulphuric acid in the presence of silver ions has been adapted to the determination of manganese in ferro- and silico-manganese and in minerals. Metaphosphoric acid is used as the stabilizing agent for permanganic acid. The method is described.

Potentiometric Determination of Manganese in Ferro-Vanadium and Vanadium-Rich Steels. A. I. Busev and N. I. Dmitrieva. (*Zavodskaya Laboratoriya*, 1950, No. 1, 29–31). [In Russian]. An analytical method is described for preparing materials containing over 0·3% of vanadium for the potentiometric determination of manganese. Manganese is precipitated as the dioxide from a solution of approx. 1 g. of sample. The precipitate is dissolved, and non-compensated potentiometric titration is carried out after the addition of sodium pyrophosphate and the careful establishment of the appropriate *p*H. Typical results are given, and these agree well with those of other methods.—S. K.

Rapid Method of Determining Ferric Oxide in the Presence of Chromium. S. T. Baliuk and V. M. Mirak'yan. (*Zavodskaya Laboratoriya*, 1950, No. 1, 100–101). [In Russian]. In the method described for determining ferric oxide in chromites and chrome–magnesites, the time required for the analysis is greatly shortened by avoiding the preliminary separation of chromium. The material (0·2 g.) is fused with pyrolusite, the product is leached out with 1 : 1 H_2SO_4, and the solution is titrated with standardized trivalent titanium solution after the addition of a small quantity of soda. The titration is carried out in the presence of potassium or ammonium thiocyanate, the end-point being marked by the disappearance of the red colour.—S. K.

Rapid Determination of Silicon in High-Chromium and Stainless Steels. V. I. Petrova. (*Zavodskaya Laboratoriya*, 1950, No. 1, 98–99). [In Russian]. The presence of nickel and chromium in relatively large concentrations interferes with the ordinary photocolorimetric determination of silicon by turning the solution green. The following method was found to give reliable results for high-chromium and stainless steels containing 0·47–0·82% silicon. HNO_3 is added to a solution of 0·1 g. in H_2SO_4, After dilution and acidification, ammonium molybdate is added in the presence of sulphuric acid sufficient to prevent the formation of molybdenum blue. 0·5% stannous chloride solution is then added, giving a coloured complex stable for 10 min. The silicon is determined by comparing the photocolorimetric results with those for a standard sample.—S. K.

Automatic Absorbing Vessel for Gas Analysis. N. A. Gruzdeva and A. A. Krivousov. (*Zavodskaya Laboratoriya*, 1950, No. 1, 113–114). [In Russian]. In the apparatus for gas analysis described, the rapid absorption of gases by liquids is achieved by rapid circulation with a solenoid pump and pulverization. The method has been successfully used for the determination of hydrogen in coke-oven gas and is also suitable for the determination of carbon monoxide.—S. K.

Determination of Gases in Ferrous Metals. Iu. A. Klyachko, A. G. Atlasov, and E. M. Chistyakova. (*Zavodskaya Laboratoriya*, 1950, No. 1, 17–13). [In Russian]. Improvements in the apparatus and procedure for the determination by vacuum fusion of hydrogen, oxygen, and nitrogen in ferrous metals are described. These include the replacement of the quartz tube by one of low-carbon steel. Optimal weights of sample for the determinations and the special conditions required for the determination of nitrogen in metal high in titanium and silicon are given. The theory of vacuum-fusion processes for ferrous-metal analyses is considered.—S. K.

Determination of Available Oxygen and Total Manganese in Manganese Oxides. R. F. Stalzer and W. C. Vosburgh. (*Analy. Chem.*, 1951, **23,** Dec., 1880). Errors, which arose when both oxygen and manganese were determined on a single sample, are discussed briefly.—T. E. D.

Analyses of Waste Gas from Open-Hearth Furnaces. E. T. W. Bailey. (*Amer. Inst. Min. Met. Eng.* : *Proc. Nat. O.H. Comm.*, 1951, **34,** 316–318). The author discusses the value of routine waste-gas analyses and considers the points and times at which samples should be taken. The method of sampling and analysing the waste gases at the Hamilton works of the Steel Company of Canada, Ltd., is briefly outlined.—G. F.

Waste-Gas Analysis. J. M. Brashear. (*Amer. Inst. Min. Met. Eng.* : *Proc. Nat. O.H. Comm.*, 1951, **34,** 318–324). The author shows how intermittent or continuous sampling of waste gases may prove to be beneficial to the successful operation of the open-hearth furnace. The application of waste-gas analyses at the Chicago plant of the Inland Steel Co. is discussed.—G. F.

The Determination of SO_2 and SO_3 in Flue Gases. P. F. Corbett. (*J. Inst. Fuel*, 1951, **24,** Nov., 247–251). This paper briefly reviews the underlying principles of an analytical method for the estimation of small traces of SO_3 in the presence of a considerable excess of SO_2, and describes its use in analysing flue gases from water-tube boilers.—J. P. S.

Estimation of Oxygen-Consuming Value of Coke-Plant Aqueous Wastes. J. A. Shaw. (*Analy. Chem.*, 1951, **23,** Dec., 1764–1767). Many oxidizable substances, often of unknown compositions, are present in coke-plant wastes. For plant design and control, a rapid and accurate method of evaluating the reducing characteristics of such wastes is required. The method described here, using chromic acid solution at 100° C. as oxidant, requires only about 12 min. for an individual test. Details of procedure are given.

A Semi-Automatic Burette for the "Dead-Stop End Point" Method. R. Morpain and J. Tranchant. (*Chim. et Ind.*, 1952, **67,** Feb., 249–252). An electronic circuit is given which will actuate an electromagnet attached to a burette, so allowing electrometric titrations to be performed automatically. The accuracy of this method on a macro- and micro-scale is indicated.—T. E. D.

HISTORICAL

Technology and History. C. Singer. (*Engineering*, 1952, **173,** Feb. 22, 246–248). A review is given of developments in skill and technology over the last 5000 years. The author links the fundamental changes in the history of mankind to the big technological achievements through the ages.—M. D. J. B.

The First Bessemer Steel Rail. A. Birch. (*Engineering*, 1952, **173,** Feb. 8, 181–182). In this brief historical note, reference is made to the origins of Bessemer steel and to the part played by Robert Forester Mushet in this invention. The first steel rail was, in fact, cast, rolled, and placed in the permanent way by Mushet himself in 1857.—M. D. J. B.

ECONOMICS AND STATISTICS

The Production of Iron in Industrial Countries. C. Tuduri. (*Chim. et Ind.*, 1952, **67,** Jan., 125–129). The factors governing the distribution of the world's iron industry are outlined, with tables giving production figures from 1870.—T. E. D.

Conservation of Strategic Metals in Germany. K. P. Harten. (*Metal Progress*, 1951, **60,** Nov., 58–63). The author prophesies that in all countries cobalt, copper, chromium, manganese, molybdenum, nickel, niobium, and tungsten will be in short supply. Means for the conservation of these metals are discussed under the headings : Conservation in steel production, conservation in processing and designing, substitution of alloys low in strategic metals, conservation and replacement of non-ferrous metals, and desirability for co-operation and research.—J. P. S.

Iron and Steel in the Soviet Union. (*World Today*, 1952, **8,** May, 210–222). Particulars of post-war reconstruction and past, present, and future production of iron and steel in the Soviet Union are presented. Pig-iron and steel production reached 22 and 31·2 million tons respectively in 1951.—R. A. B.

The Dutch Iron and Steel Industry. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1951, **26,** Nov., 1–5). Dutch crude steel output is planned to increase from the present 500,000 to about 800,000 tons by 1952/53. Consuming 1,200,000 tons of finished steel products annually, Holland has replaced Sweden as Europe's largest importer. An agreement with the United Kingdom gives the Dutch the option to import shipbuilding sections and plates from Great Britain up to

the end of 1952, in exchange for 50,000 to 60,000 tons of pig iron per year.—E. C. S.

Growth of Brazilian Industry. (*Wire Production*, 1951, **1**, Dec., 39–41). Statistics and other general information are given about the Brazilian steel industry and wire production.

MISCELLANEOUS

The Plant in Action—Laboratory Work in Development and Research. A. J. K. Honeyman. (*Iron Coal Trades Rev., Special Issue*, 1951, 164–168, 183). The author discusses the work of the laboratories serving the Abbey works and the Port Talbot and Margam works of the Steel Company of Wales, Ltd., and the part they play in quality control and production research. A feature of the laboratories is the installation of Lamson tube circuits for the conveyance of samples and analytical reports between the melting shops and laboratories.—G. F.

The Plant in Action—Traffic Control. A. J. Harby. (*Iron Coal Trades Rev., Special Issue*, 1951, 158–163). The author describes the organization and operation of the traffic department serving the combined Port Talbot, Margam, and Abbey works of the Steel Company of Wales, Ltd. A feature of the control is the fitting of short-wave wireless transmitters to the locomotives handling the ingot traffic.—G. F.

The Engineer and Accident Prevention in Iron and Steel Works. G. P. Barnett. (*J. Iron Steel Inst.*, 1952, **171**, July, 290–295). [This issue].

The Prevention of Handling and Lifting Hazards. A. Taylor. (*J. Iron Steel Inst.*, 1952, **171**, July, 299–305). [This issue].

Particle Size Determination by Centrifugal Pipet Sedimentation. H. J. Kamack. (*Analy. Chem.*, 1951, **23**, June, 844–850). Size analysis of dusts in the range 0·1–2 μ can be performed in the apparatus described. Formulæ are derived for calculating particle-size distributions from the experimental data.—T. E. D.

A Recording Dust Meter. B. O. Smith and S. S. Carlisle. (*J. Iron Steel Inst.*, 1952, **171**, July, 273–276). [This issue].

Silicosis. R. Genot. (*P.A.C.T.*, 1952, **6**, Feb., 19–29). The causes, mode of action, and treatment of silicosis are described. Statistics on its prevalence in various occupations are given.—T. E. D.

BOOK NOTICES

GOETZEL, C. G. "*Treatise on Powder Metallurgy.*" Volume III. "*Classified and Annotated Bibliography.*" 8vo, pp. xxiv + 899. New York, 1952: Interscience Publishers, Inc.; London: Interscience Publishers, Ltd. (Price £8 16*s.*)

This volume completes Goetzel's 'Treatise,' the most comprehensive survey of the literature on powder metallurgy yet published, which is recognized as a standard work of reference on the subject (the two earlier volumes were on "Technology of Metal Powders and Their Products" and "Applied and Physical Powder Metallurgy"). It consists of no fewer than 11,865 annotated references to published literature and patents, which are essentially concise indicative abstracts giving clear information to the reader as to whether or not he will be interested in searching out the original source. The material is drawn from several earlier bibliographies, supplemented by information from the author's and other card indexes; it includes American, British, German, French, Austrian, Norwegian, Swedish, Danish, Dutch, Italian, Czechoslovakian, Russian, Hungarian, Swiss, Belgian, Japanese, Canadian, Australian, and Indian references. In this volume, much of the material of the reports by Allied government agencies (*e.g.*, B.I.O.S., C.I.O.S., F.I.A.T.) has been introduced by references.

The scope of the work is wide, covering the art and science of manufacturing useful articles from metal powders and of producing powders, and it includes many 'marginal' items such as pigments, coatings, and catalysts, and equipment used in this field that has other applications. The bulk of the references apply to the literature of the last hundred years. but earlier relevant theoretical and practical work, from the XIth century onwards, is noted. The references are taken, in time, up to January, 1950, with the addition of a few items from 1950 publications, and some 20 important papers from the 1949 "Symposium on the Physics of Powder Metallurgy," which were not published in book form until 1951. Patents are quoted by year of issue, to facilitate searches; in American references the name of the inventor is given, and (where possible) the assignee: for other countries the company owning the patent is cited, and (where possible) the inventor's name.

The arrangement of the separate literature and patents sections is logical, and conforms closely with the textual arrangement of volumes I and II, so that the reader can rapidly check the available sources of reference to any subject in the text. The classification commences with a 12-page table of contents, and is continued by comprehensive name and subject indexes; additionally, there is a cross index to patents, which gives a complete and rapid means of reference in this volume to every patent mentioned in volumes I and II. The material under every sub-heading is arranged historically. A guide to the use of the bibliography clearly explains the best way of searching for references, and is particularly helpful in dealing with items which are classifiable under more than one sub-heading.

The main subject headings are: Powder metallurgy, general; production and composition of powders; powder processing methods and equipment; powder-metallurgy products, composition, properties, and manufacture; and theoretical discourses. The principal ferrous materials and products mentioned are engineering parts from iron, steels, alloys, and composite materials; special magnetic and electrical parts of controlled properties; porous bearings and filters; wear-resistant parts; means of producing coatings of several types on iron or steel; and magnetic fluid clutches.

The wealth of information contained in this volume ensures that it will be invaluable to all concerned with powder metallurgy, whether metallurgists, engineers, students, patent agents, or librarians. The book is clearly and attractively printed, but the reader must be patient with occasional typographical errors and lapses from strict alphabetical order in the indexes.—K. E. JERMY

HANSTOCK, R. F. "*The Non-Destructive Testing of Metals.*" Institute of Metals Monograph and Report Series No. 10. 8vo, pp. viii + 163. Illustrated. London, 1951: The Institute of Metals. (Price 21*s.*)

This book restates certain sections of the sciences, mainly classical physics, that have a particular bearing on the non-destructive examination of metals. No reference is made to electron microscopy and only a brief reference to recent developments in hardness testing; the theoretical aspects of all other methods are, however, superficially covered, but the book fails to provide explicit solutions to specific problems of non-destructive testing.

The first chapter is of an introductory nature. Then follows a chapter devoted to the measurement of thickness of a layer of metallic or non-metallic material, deposited on a metal base, without removing a portion of the layer; seven methods are considered, *viz.*: Capacity method, transformer method, method depending on the attraction of a magnet, inductance method, resistance method, methods depending on absorption and scattering of penetrating radiation, and ultrasonic methods.

In the next four chapters the author seeks to cover the detection of cracks at or near the surface, radiography, detection of flaws by ultrasonic methods, and dynamic tests.

Chapters 8, 9, and 10 deal with damping capacity measurements, and chapters 11 and 12 with the application of X-ray diffraction for the identification of composition, measurement of inter-planar spacing, strain and residual stresses, and for the estimation of grain size and the determination of grain orientation. Chapter 13 briefly covers electrical and magnetic methods for estimating composition and condition, and chapter 14 consists of four pages of text and a page of references relating to some methods of analysis.

The author has tried to cover too much in in too small a space.—J. FERDINAND KAYSER

"*Refractories Bibliography*, 1928–1947, *Inclusive.*" Published by the American Iron and Steel Institute and

American Ceramic Society, Inc. La. 4to, pp. 1087. Columbus, Ohio, 1950 : American Ceramic Society. (Price $15)

This publication consists of 2044 columns of 8–10 abstracts, each arranged alphabetically according to authors, where these are known ; where they are unknown, the first word of the title, omitting the definite or indefinite article, or the name of the society or firm responsible, is used instead. A subject index of about 60 pages follows. The abstracts have been reproduced from many sources, including this journal and the *Journal of the Institute of Metals*, and they vary greatly in length and quality, and include a large number of patents. However, this volume should be very useful to all who use or study refractories.—J. P. S.

SILMAN, H. "*Chemical and Electro-Plated Finishes—The Protective Treatment of Metals.*" With a Foreword by H. Moore. Second Edition, revised. 8vo, pp. xv + 479. Illustrated. London, 1952 : Chapman and Hall, Ltd. (Price 50*s.*)

Mr. Silman has chosen an appropriate moment to publish a second edition of his now well-known book, in that an authoritative work summarizing the most recent developments on the subject is distinctly valuable at this juncture when metal finishing is so important to the national economy. He has taken considerable pains in revising the original work, and the result is a comprehensive presentation of the principal aspects of finishing by chemical and electroplating means. The book is as up-to-date as the deplorable lag, which has existed in the last few years in the publishing industry, can permit any author to achieve today, and it is for this reason that it is no fault of the author's that there is no reference to some important relatively recent work such as, for example, tin–nickel alloy deposition or chromizing.

The main merits of the book are that it is well-balanced and the exposition is clear. The first half of the book opens, very desirably, with a useful chapter on the corrosion of metals and alloys, and then deals successively with descaling and pickling processes, polishing, degreasing and cleaning, and finally metal colouring, before proceeding to a consideration of electroplating processes. In the second half of the book, all the important deposited metals are dealt with, including nickel, copper, chromium, tin, cadmium, zinc, lead, and the precious metals, concluding with the finishing of the light alloys. The author has revised or added numerous sections dealing, for example, with pickling processes, polishing methods, the cleaning of metal surfaces, descriptions of plant which include effluent and fume disposal, and periodic reverse current copper-plating and nickel-coating processes (both immersion and deposition).

The book is well-produced and illustrated, and represents a useful and welcome addition to the literature of metal finishing.—S. WERNICK

TRINKS, W. "*Industrial Furnaces.*" vol. I. 4th edition. 8vo, pp. xi + 526. Illustrated. New York, 1951 : John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. (Price $10.)

Those familiar with earlier editions of this book will know the particular scope of the present volume, but, for potential and new readers, the title is not as informative as it might be, because the treatment is actually limited to the design of heat-treatment and reheating furnaces, or, as the author puts it, "those furnaces in which heat is imported for the purpose of raising temperature and in which no chemical changes or changes of state such as melting or vaporization are intended to take place." The book is, in fact, intended for furnace engineers.

Briefly, the author deals with the principles of heating capacity, fuel economy and heat-saving devices, the strength of furnaces and furnace materials, and the movement of gases in furnaces. Although very short mention is made of electric resistance and induction heating, the author is mainly concerned with furnaces heated by the combustion of fuel. The book provides much useful basic and practical material on the design of such furnaces, with worked-out examples at appropriate places in the text. To make the fourth edition, a good proportion of the text has been rewritten, new illustrations have been added, data have been brought up to date, and various new matter has been incorporated. The large Appendices contain for the most part 'calculation methods which, although very helpful, are seldom used.'

When the reviewer first started writing a technical book, he was told by his publisher that he spent too much time in the text saying what he was going to do. Perhaps this has made him rather biased, for such explanation is undoubtedly useful to the reader at times, but it is felt that the present author is a little too inclined in this direction. However, it must be stressed that the writing is perfectly clear. The book is excellently produced and, in the reviewer's opinion, constitutes a valuable handbook for furnace designers and the like.—A. R. BAILEY

VOGEL, ARTHUR I. "*Text-Book of Quantitative Inorganic Analysis,*" Theory and Practice, 2nd edition. 8vo, pp. xxiii + 918. Illustrated. London, 1951. Longmans, Green and Co., Ltd. (Price 48*s.*)

Twelve years have elapsed since the publication of the first edition of Vogel's excellent textbook, and many developments in inorganic analytical chemistry have taken place during this time, including the widespread adoption of instrumental techniques of analysis. The author has covered these changes by the introduction of several new chapters on instrumental methods and micro-analysis, and by giving many new determinations of elements and radicals in the body of the old chapters. In effect, this is an entirely new book ; on the reviewer's bookshelf it dwarfs the previous edition.

The author states that the book is intended both for the student and for the practising chemist. The reviewer agrees that the needs of the student are amply covered, but the 400 pages (nearly half the book) devoted to the techniques of classical and instrumental analysis are largely wasted on the competent analyst. Such a person would prefer to have further knowledge of the general methods outlined, their limitations and their accuracy. Even so, these details can seldom be fully comprehended without consulting the original papers, and it is regrettable that, in order to save space, only general bibliographies have been given.

A novel feature of the book is the detailed instructions for the construction of several types of electrochemical analytical apparatus ; even a suitable solder is listed.

There are few errors, but the author does perpetuate the statement that phosphomolybdic anhydride is hygroscopic : it is not. On page 160 the weight of one litre of oxygen should be 1·31 g.

The book is written and illustrated with the author's customary care, and he is to be congratulated on producing a worthy successor to the first edition.—J. B. BOOKEY

NEW PUBLICATIONS

"*The All-Basic Open-Hearth Furnace.*" Being also the Report of the 36th Steelmaking Conference, held at Ashorne Hill, Leamington Spa, on 2nd–3rd May, 1951. Prepared by the All-Basic Open-Hearth Furnace Sub-Committee of the British Ceramic Research Association and the British Iron and Steel Research Association. The Iron and Steel Institute, 1952, Special Report No. 46. La. 4to, pp. vi + 92. Illustrated. London, 1952 : The Iron and Steel Institute. (Price : Members 15*s.*, non-members 25*s.*)

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ERIC TURNER GILL was born in Sheffield in 1904. He was educated at Sheffield Central Secondary School and later at Sheffield University, where he graduated B.Sc. in 1925.

After graduation Mr. Gill took up his first appointment as Steelworks Chemist with Hadfields Limited. Three years later he was appointed Assistant Metallurgist with Samuel Fox and Co., Limited, of Stocksbridge, near Sheffield. In 1931, he joined Messrs. Bruntons Limited, of Musselburgh, and, after twelve months, was appointed Chief Metallurgist and Chief Chemist. During his employment with Messrs. Bruntons Limited, Mr. Gill carried out research work on the fatigue properties of steel wire, and two papers on this subject were published in the ' Journal.' For the continuance of this work, he was awarded a Carnegie Scholarship in 1936.

In that year, Mr. Gill was appointed Metallic Materials Inspector with the Aeronautical Inspection Directorate of the Air Ministry, but left after two years to join Imperial Chemical Industries, Limited. For two years he was Metallurgist and Metallic Materials Investigator and Adviser at the Billingham Division; then he was transferred to Sheffield, where he held the position of Metallurgist to the Inspecting Engineers Department. In 1943 he was seconded for two years to Firth-Vickers Stainless Steels Limited, being appointed Works Manager of their Ministry of Aircraft Production Factory at Barnsley.

In 1946 Mr. Gill returned to Sheffield to take up the post of Deputy Chief Metallurgist with Messrs. Edgar Allen and Co., Limited. During his time with this firm he served on two committees of the Steel Castings Division of the British Iron and Steel Research Association. In October, 1949, he was appointed Metallurgist to the Climax Molybdenum Company of Europe, Limited.

Mr. Gill was elected President of the Sheffield Metallurgical Association in 1950. He has been a Fellow of the Institution of Metallurgists since 1946. He is also a member of the Physical Properties Panel of the Research and Development Division of the British Steel Founders' Association. He has been a Member of The Iron and Steel Institute since 1941.

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Honorary Member of Council, 1950-51